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1. FOREWORD

The *SARPLAST* filament-wound glass reinforced thermosetting resin pipe systems (polyester and vinylester) offer superior corrosion resistance and a combination of high mechanical and physical properties which have been proved in the most severe operating conditions all over the world.

The purpose of the *Iniziative Industriali PIPING MANUAL* is to provide engineers with a useful tool for the design, specification and installation of *SARPLAST PLASTIWIND* (glass-fiber-reinforced thermosetting-resin pipe) and *SARPLAST PLASTISAND* (glass-fiber-reinforced plastic-mortar pipe), for aboveground, below-ground and submarine installations.

The information provided by this *PIPING MANUAL* are widely applicable to diameter size ranging from 25 to 3000 mm. Anyway, for diameter larger than ND1200 or for not standard application it is suggested to contact the technical department of Iniziative Industriali to identify the appropriate solutions.

As a result of experience, gained in over 25 years of engineering GRP piping systems, we are able to suggest solutions to a wide variety of service conditions and to find the most suitable solution to new technical requirements.

Fields covered by *SARPLAST GRP* products are the following:

a - water distribution (civil and industrial)

b - sewer systems (urban and industrial)

c - irrigation networks

d - water intakes for cooling water systems

e - waste water outfalls to sea

f - sub-sea pipelines

g - process lines for industrial plants

h - fire fighting networks

i - corrosive fluids and vent gas stacks

l - wells casing, wells pumps risers and screen

m - penstocks

p - pipes for ships and offshore application

Important Notice

It is intended that this document be used by personnel having specialized training according to standard industry practice and normal operating conditions.

All information was correct at the time of issue of the document. Variations of any products or systems, described in this brochure, can be done without prior warning.

We do not accept any responsibility for the accuracy of statements made.

2. CODES AND STANDARDS

The governing documents commonly used in specifying, testing and applying GRP piping are the following:

Product Specifications and Classifications

ANSI/AWWA C950-95	Standard for Fiberglass Pressure Pipe
ASTM D2310	Standard Classification for Machine-Made Reinforced Thermosetting-Resin Pipe
ASTM D2996	Standard Specification for Filament-Wound "Fiberglass" (Glass-Fiber Reinforced Thermosetting-Resin) Pipe
ASTM D3262	Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe
ASTM D3517	Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe
ASTM D3754	Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe
ASTM D4161	Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals
BS 5480 - 90	British Standard Specification for Glass reinforced plastics (GRP) pipes, joints and fittings for use for water supply or sewerage.
BS 7159 - 89	Design and construction of glass reinforced plastics (GRP) piping systems for individual plants or sites
UNI 9032	Tubi di resine termoindurenti rinforzate con fibre di vetro (PRFV) con o senza cariche. Tipi, dimensioni e requisiti.

Recommended Practices

ASTM C581	Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service
ASTM D2488	Standard Practice for Description and Identification of Soils
ASTM D2563	Standard Practice for Classifying Visual Defects in Glass-Reinforced Plastic Laminate Parts
ASTM D2992	Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings Procedure B - Steady pressure

ASTM D3567	Standard Practice for Determining Dimensions of Reinforced Thermosetting Resin Pipe (RTRP) and Fittings
ASTM D3839	Standard Practice for Underground Installation of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe
BS 8010	B.S. Code of practice for Pipelines - Section 2.5 Glass reinforced thermosetting plastics

Test Methods

ASTM D1598	Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
ASTM D1599	Standard Test Method for Short Term Hydraulic Failure Pressure of Plastic Pipe, Tubing and Fittings
ASTM D2412	Standard Test Method for Determination of External Loading Characteristics of Plastics Pipe by Parallel-Plate Loading
ASTM D2924	Standard Test Method for External Pressure Resistance of Reinforced Thermosetting-Resin Pipe
ASTM D3681	Standard Test Method for Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition
BS 5480-90	British Standard Specification for Glass reinforced plastics (GRP) pipes, joints and fittings for use for water supply or sewerage
UNI 9033	Tubi di resine termoindurenti rinforzate con fibre di vetro (PRFV) con o senza cariche. Metodi di prova.

Fittings and Flanges

Fittings and flanges comply with the following standard:

U.S. Department of Commerce, National Bureau of Standard Voluntary Product Standard

PS 15-69, Custom Contact-Molded Reinforced Polyester Chemical-Resistant Process Equipment.

3. QUALITY ASSURANCE

Iniziative Industriali Quality Assurance System is in accordance with **ISO 9001.**

The Quality System has been certified by DNV.

SARPLAST GRP products have been also certified by the following institutes:

- **BUREAU VERITAS**
- **DNV** Det Norske Veritas
- **FM** Factory Mutual
- **KIWA**
- **Lloyd's Register**
- **NSF** National Sanitation Foundation
- **RINA** Registro Navale Italiano

4. CLASSIFICATION OF PIPES AND FITTINGS

Nominal Diameter

Nominal size of pipe and fitting is based on internal diameter. The complete list of the available size produced by *Iniziative Industriali* is in table 4.1.

Nominal Pressure Classes

Pipes and fittings are classified according to nominal pressure. Standard pressure classes are 4, 6, 10, 16, 20 and 25 bar. Intermediate or higher pressure classes are considered on request or depending on the design conditions.

Specific Pipe Stiffness Classes

Pipes are also classified according to specific pipe stiffness. Standard stiffness classes are 1250, 2500, 5000 and 10000 Pa. Intermediate or higher stiffness classes are available on request or depending on the design conditions.

The standard GRP pipes and fittings produced by *Iniziative Industriali* are described in the document *GRP PIPING PRODUCT LIST*.

Tab 4.1 - List of Nominal sizes (ND) produced by Iniziative Industriali

mm	inch	mm	inch	mm	inch	mm	inch	mm	inch
25	1	200	8	600	24	1000	40	1900	76
40	1 1/2	250	10	650	26	1100	44	2000	80
50	2	300	12	700	28	1200	48	2200	88
65	2 1/2	350	14	750	30	1300	52	2400	96
75	3	400	16	800	32	1400	56	2500	100
100	4	450	18	850	34	1500	60	2600	104
125	5	500	20	900	36	1600	64	2800	112
150	6	550	22	950	38	1800	72	3050	120

5. JOINTS

GRP pipe joints include two general categories:

a) unrestrained joints**,** which can withstand only hoop pressure;

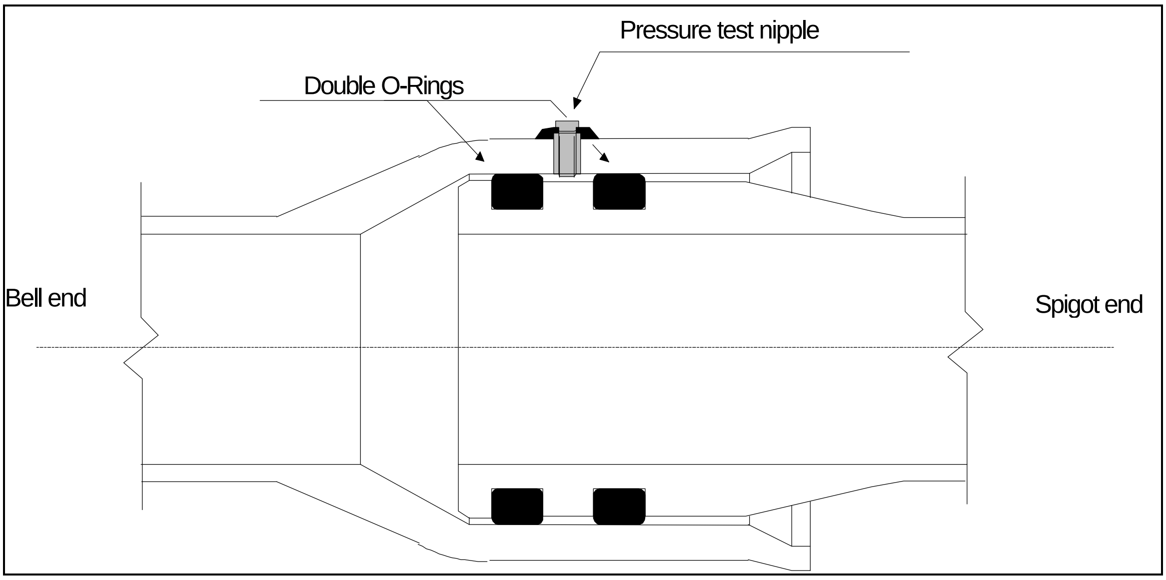
b) restrained joints**,** which can accommodate also longitudinal forces.

5.1 Unrestrained joints

Double O-ring Bell and Spigot Joint (B/2R)

Standard joint is the double O-ring type. The bell is integral at one end of the pipe and the spigot is the other end..

The hydraulic sealing is performed by means of two elastomeric O-rings, installed in circumferential parallel grooves machined on the spigot. By inserting a nipple through the bell and between the gaskets, one can test the joint immediately after assembly using an hydrostatic techniques. This seal check gives high reliability to the installation and may allow to avoid the final hydrostatic test. Application of nipple is standard for ND > 250.



The double O-ring bell and spigot joint allows for angular deflection. The following table contains the maximum recommended values to be used for installation design according to BS 5480.

Tab. 5.1 - Maximum recommended values for installation design

Nominal sizes (ND)	Angular deflection
mm	degrees
< 500	3
>= 500 to < 900	2
>= 900 to < 1800	1
> 1800	0.5

Application field

Diameters	Pressures
25 mm to 500 mm	up to 30 bar
550 mm to 1200 mm	up to 20 bar
1300 mm to 3000 mm	up to 16 bar

<u>Higher pressure can be supplied on request.</u>

The axial forces have to be sustained by external devices.

Mechanical Coupling Joint

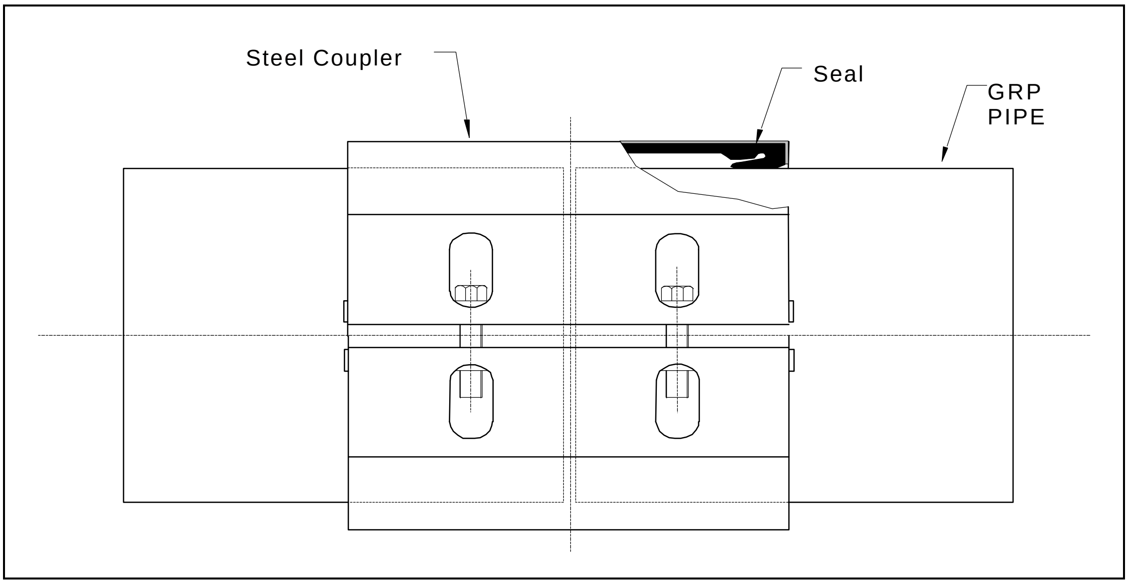
Mechanically coupled joints typically seal on the OD of plain end pipes through the use of gaskets that are compressed to effect the seal.

Most of the commonly available mechanical couplers can be used to join *SARPLAST* pipes.

Application field

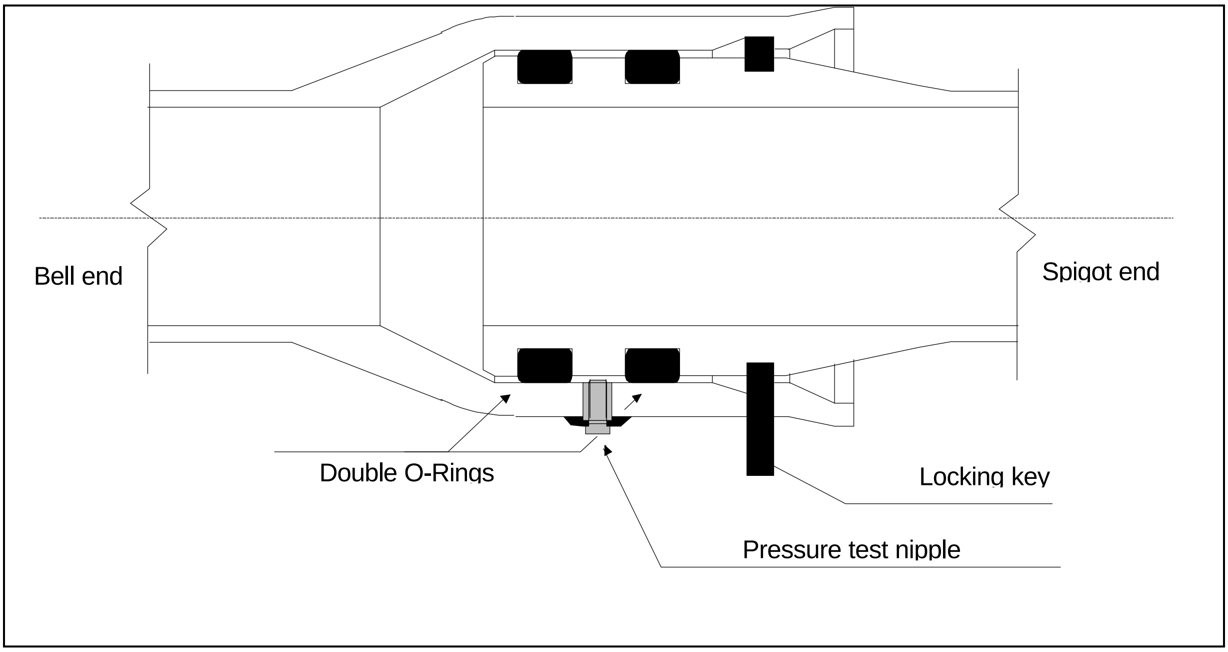
Diameters : 75 mm up to and including 3000 mm

Pressures : up to 16 bar



5.2 Restrained joints

Double O-ring Bell and Spigot with locking key Joint (B/2RLJ)



The joint is a double O-ring Bell and Spigot type with a locking device, that can be inserted through a bell opening into a groove. Both metallic and shear resistant plastic materials are used for this device.

This joint is a non-destructive, separable joining system which accommodate longitudinal forces.

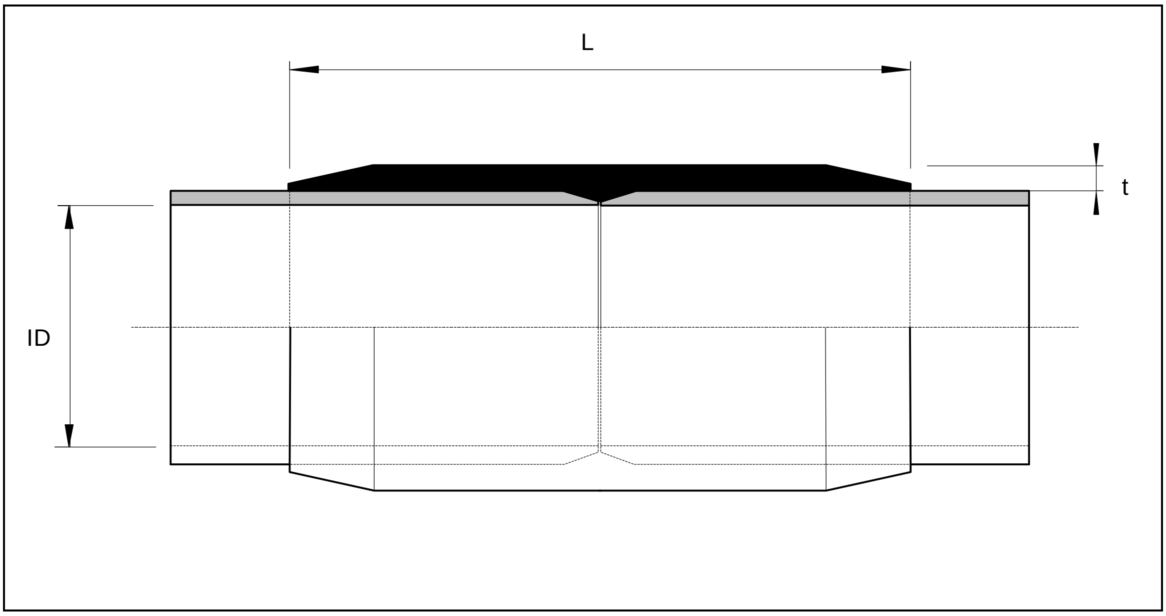
Also the double O-ring bell and spigot joint with locking key allows for angular deflection. The maximum recommended values to be used for installation design are the same indicated in Tab. 5.1.

Application field

Diameters	Pressures
25 mm to 500 mm	up to 30 bar
550 mm to 1200 mm	up to 16 bar
1300 mm to 3000 mm	up to 10 bar

Higher pressure classes can be produced on request.

Butt and Strap Joint



This permanent joint consists of a hardening of impregnated glass, mats and tissues which are laminated according to specified width and thickness.

The laminated joint provides continuity in both hoop and axial directions.

The application field of Butt & Strap joint is related to diameter and pressure classes of pipes and fittings to be joined.

The dimensions of butt and strap joint are calculated according to the following formulae:

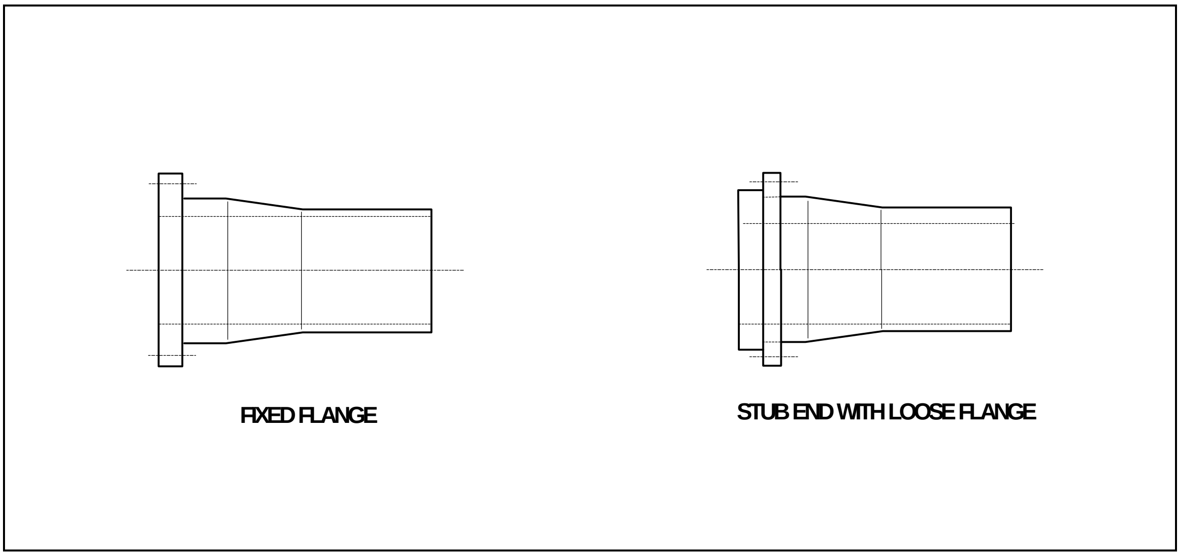
$t = P(ID+2t_p)/(2\sigma_{all}-P)$

$L = P\ (ID+2t_p)/(2\tau_{all})$

where:

t	= *thickness of lamination, mm*
P	= *design pressure, MPa*
ID	= *pipe internal diameter, mm*
L	= *length of lamination, mm*
tp	= *pipe thickness, mm*
s_{all}	= *allowable hoop stress, MPa*
t_{all}	= *allowable shear stress, MPa*

Flanged Joint



GRP flanges are available to meet drilling according to ANSI, DIN, BS, UNI etc.

Flanges are of two type: Fixed Flange (F/F) and Stub end with steel Loose Flange (F/L).

Each type of flange is available with plain end, spigot end and bell end.

Sealing between flanges is accomplished with an elastomeric gasket. Standard gasket is a flat gasket. For severe application that can be identified by Iniziative Industriali Tecnichal Department, and in any case for diameter >1200 mm and NP > 10 bar, it is suggested to use O-ring gasket that are accomodate in a groove realized on the face of the flange.

Application field

Diameters	Pressures
25 mm to 500 mm	up to 30 bar
550 mm to 1200 mm	up to 16 bar
1300 mm to 3000 mm	up to 10 bar

The torque values depend on the pipe size, the nominal pressure and on on the application. Assemble the joint and finger tighten all nuts. Make sure bolt threads are new and oiled so that proper torque results are attained. Use washers under both nuts and heads to protect back-facing of flanges.

6. RAW MATERIALS

Basic raw materials used for manufacturing of SARPLAST GRP PIPES are the following:

- Resins
- Glass reinforcements
- Auxiliary raw materials

6.1 RESINS

Sarplast pipe can be manufactured using the following types of resin:

- Isopthalic Polyester
- Vinylester (epoxy bisphenol-A, vinyl- urethanic, epoxy novolac)
- Bisphenol Polyester
- Special resins (for high temperatures, fire retardance, abrasive resistance, etc.)

The above resins show several interesting characteristics such as:
- curing at room temperature
- low toxicity during handling and curing
- high chemical resistance
- good adhesion to glass fibers.

Isophthalic Polyester has a good corrosion resistant to water and fluids with low acid content up to a maximum operating temperature of about 60 °C.

Bisphenol Polyester resin shows a high chemical inertness to both strong acids and bases also at elevated temperature.

Vinylester resin combines a very good chemical inertness to strong acids and bases with high mechanical properties of the laminates. The suggested uses are applications where either chemical resistance and toughness are needed.

For equipment where higher temperature resistance or specific properties like flame retardance, conductivity or enhanced abrasion resistance are needed, special formulated vinylester resins are used.
Some typical properties of liquid resins are:

Property	Isophtalic	Bisphenol	Vinylester
Styrene level, %	48	48-50	45-48
Brookfield viscosity, mPa.s at 25 °C	400	450	500
Specific gravity uncured at 25 °C [g/cm^3]	1.07	1.03	1.02
Storage stability months	6	6	6

The cured resin has the following properties at room temperature:

Test	Isophtalic	Bisphenol	Vinylester
Tensile strength, MPa	80-90	60-70	81-83
Tensile modulus, GPa	3.0-3.9	3.0-3.5	3.3-3.5
Flexural strength, MPa	-	110 -125	124 -153
Flexural modulus, GPa	-	3.0 - 3.5	3.1-3.5
Heat distortion temperature, °C	95-115	100-120	102-115
Barcol hardness	35-40	35-40	35-40

Resin properties are checked on each single batch according to Iniziative Industriali Quality Control and Inspection Test Plan.

6.2 GLASS REINFORCEMENTS

Types of glass used for manufacturing GRP are the following:

- "C" glass chemical-resistant hydrolytic grade III DIN 12111
- “E” glass with excellent mechanical and electrical properties acc. to ISO 2078

Typical glass reinforcements used are:

- - surfacing "C" veil, consisting of randomly dispersed glass fibers bonded into sheet by a polyester resin generally used as reinforcement for the first layer of the laminate
- - CSM (chopped strand mat) "E" glass, made of chopped strands bonded in mat form with a powder binder and used in hand lay-up or contact molding processes.

- \- CR (continuous roving) "E" glass specially designed for fast wet-out, good processing and handling characteristics as well as excellent adhesion with polyester and vinylester used in filament winding processes.
- \- WR (woven roving) “E” glass composed of direct roving woven into a fabric and designed to be compatible with most polyester hand lay-up resins.

The more significant mechanical properties of fiberglass used as reinforcement are the following:

Property	Value
Ultimate tensile strength, MPa	1.400
Modulus of elasticity, GPa	70

The glass fiber surface is treated with agents to prevent damages to the fiber and to improve the compatibility with the resin. These agents are Silan-organic substances.

6.3 AUXILIARY RAW MATERIALS

Auxiliary raw materials are all the technological additives used for processing of reinforced resins such as promoters, accelerators, catalysts, inhibitors, viscosity and density additives, aggregates, filler and pigments .

7. FABRICATION

7.1 PIPES

7.1.1 Fabrication methods

Pipes are manufactured using the discontinuous filament winding process on computer controlled machines (CAM).

By adjusting the relative speed of mandrel rotation and glass distribution head movement, helical reinforced layers with different angles can be wound.

The inside diameter of the finished pipe is defined by the mandrel outside diameter and the designed wall thickness is achieved by repeated passes. Therefore the outside diameter of pipe (OD) is determined by the pipe wall thickness.

In order to increase the pipe stiffness, specially on large diameter pipes, silica sand can be added to parallel layers of the mechanical wall.

Main characteristics of this process are the following:

- bell and spigot ends are monolithic with the pipe wall

- optimisation of axial and hoop characteristics can be obtained by changing the winding angles

- axial strength normally higher than pipes produced with other processes

- pipe stiffness is not related to joint stiffness that is in any case higher than pipe stiffness

Pipes manufactured using the Discontinuous Filament Winding process are used either for above ground and underground installations, with gravity flow, medium and high internal pressure.

7.1.2 Wall structure

GRP pipe wall consists of three layers perfectly adherent one to the other and each having different characteristics and properties in relation to their function.

Liner

Liner or chemically resistant layer is the internal layer of the pipe; it is in direct contact with the conveyed fluid. This layer has the function to guarantee the resistance to the chemical corrosion and the impermeability of the whole pipe.

Liner has the internal surface, namely the one in contact with the conveyed fluid, particularly smooth. This characteristic of smoothness reduces to minimum the fluid head losses and pumping heads and opposes to the growth of mineral deposits and algae. Liner is made of two monolithic sub layers: the inner one, in direct contact with the fluid, is reinforced with glass veil "C" 33 g/m^2, with ratio resin content in a range of 80% - 90% by weight, the outer one is reinforced with plies of glass mat "E" of 375 g/m^2 , with a resin content in a range of 60% - 70% by weight.

Standard liner thickness is about 0.8 - 1.2 mm, higher thickness can be produced on request.

Mechanically resistant layer

Glass reinforced layers guarantee the mechanical resistance of the whole pipe against stresses due to internal and/or external pressure, external loads due to handling and installation, thermal loads.

The layer is obtained by applying, on the previous partly cured liner, continuous rovings of glass wetted with resin, under controlled tensioning. This layer can contain aggregates (inert

granular material such as silica sand) in order to increase the stiffness of the whole pipe. Thickness of mechanical resistant layer depends on the design conditions.

Top coat

Top coat or gel coat is the outer layer of the pipe which consists of pure resin added with UV protectors to protect the pipe from sun exposure.

In case of severe exposure conditions, i.e. aggressive soils or very corrosive environment, the gel-coat can be reinforced with a surfacing veil or added with fillers or pigments.

7.2 FITTINGS

7.2.1 Fabrication methods

Fittings are manufactured by the hand lay-up, contact molding and spray-up process.

In hand lay-up and contact molding processes veil and alternate layers of mat and woven roving saturated with resin are applied on the mold. The operation is repeated until the required thickness is achieved.

In spray up process continuous strand roving is fed through a chopper gun, combined with catalyzed resin, and sprayed onto the mould surface. The operation is repeated to reach the required thickness.

7.2.2 Wall structure

GRP fitting wall such as the pipe wall consists of three layers perfectly adherent one to the other in order to have a monolithic structure, each having different characteristics and properties in relation to their function. Liner and top coat are the same as the pipe. The difference consists in the mechanical resistant layer due to the type of reinforcement used.

8. PROPERTIES OF LAMINATES

The following tables refer to laminated obtained by the filament winding process having a winding angle of 55 degrees.

Mechanical properties

Property	Pipe	Fitting	
Ultimate hoop tensile strength	220-250	110-150	N/mm^2
Ultimate axial tensile strength	110-130	110-150	N/mm^2
Ultimate hoop flexural strength	330-370	130- 170	N/mm^2
Hoop tensile modulus (Eh)	20.000-25.000	9.000-13.000	N/mm^2
Axial Tensile modulus (El)	10.000-14.000	9.000-13.000	N/mm^2
Hoop flexural modulus (Ef)	20.000-25.000	9.000-13.000	N/mm^2
Poisson's ratio for applied hoop stress, ν_{hl}	0.5-0.55	0.3	
Poisson's ratio for applied axial stress, ν_{lh}	ν_{hl} *El/Eh	0.3	

Thermal and other physical properties

Property	Pipe	Fitting	
Glass content (by weight)	65 - 75	35 - 50	%
Specific gravity	1.850	1.650	kg/m^3
Coeff. of linear thermal expansion	$1.8*10^{-5}$ - $2.2*10^{-5}$	$1.8*10^{-5}$ - $2.2*10^{-5}$	1/°C
Thermal conductivity	0.26	0.26	W/m*K
Electrical resistivity (standard pipe)	10^9	10^9	Ohm/m
Electrical resistivity (conductive pipe)	$<10^5$	$<10^5$	Ohm/m

9. HYDRAULIC CHARACTERISTICS

GRP pipes, thanks to their smooth internal surface, their resistance to corrosion and to the absence of fouling, have excellent hydraulic characteristics and provide economic advantages over other material pipes.

9.1 PRESSURE LOSS CALCULATIONS

A number of different calculation methods help to determine the head loss for pipes and fittings. The most common are the Darcy-Weisbach formula with Colebrook friction factor, Hazen-Williams and Manning formulae.

The inner surface of GRP pipe has an absolute roughness of 25 μm.

When the joint system is B/2R or B/2RLJ the equivalent absolute roughness of the pipeline is 70 μm.

Darcy-Weisbach formula

$$J = \frac{fv^2}{2gD}$$

where:

g = *gravity constant, 9.81 m/s^2*
J = *head loss, m/m*
v = *velocity, m/s*
D = *inside diameter, m*
f = *friction factor (from the Colebrook equation):*

$$\frac{1}{\sqrt{f}} = -2\mathrm{Log}\left(\frac{\varepsilon}{3.71D} + \frac{2.51}{Re\sqrt{f}}\right)$$

where:

e = long term absolute roughness, (70 mm for GRP)
Re = vD / ν = Reynold's number, dimensionless
*n =kinematic viscosity, m^2/s (1.14 * 10^{-6} at 15°C for water)*

Hazen-Williams formula

$$v = 0.85CR^{0.63}J^{0.54}$$

where:
v = *velocity, m/s*
C = *Hazen-Williams coefficient, (145 for GRP)*
R = *hydraulic radius, m*
J = *hydraulic gradient, m/m*

Manning formula

$$v = \frac{1}{n}R^{0.667}J^{0.5}$$

where:
v = *velocity, m/s*
n = *Manning's coefficient, (0.01 for GRP)*
R = *hydraulic mean radius, m*
J = *hydraulic gradient, m/m*

Max recommended fluid velocity

Clear fluid	up to 4.0 m/s max
Corrosive or erosive fluids	up to 2.0 m/s max

Head loss in fittings

The head loss H (m) in fittings can be determined using K factor:

$$H = K\frac{v^2}{2g}$$

where typical K factors for fiberglass fittings are illustrated in table 9.1.

Tab. 9.1 - Typical K factors for GRP fittings

Type of fitting	K factor
90° elbow, std.	0.5
90° elbow, single miter	1.4
90° elbow, double miter	0.8
90° elbow, triple miter	0.6
45° elbow, std.	0.3
45° elbow, single miter	0.5
Tee, straight flow	0.4
Tee, flow to branch	1.4
Tee, flow from branch	1.7
Reducer, single size reduction	0.7

The graphs in the following pages give a quick methods to obtain the head losses of a pipeline for a selected velocity of fluid, for the range of size ND 50 - ND 700, the graph at page 26, and ND 800 - ND 2800, the graph at page 27.

9.2 SURGE PRESSURE (WATER HAMMER)

The magnitude of surge pressure is highly depending on the hoop tensile modulus of elasticity and on the thickness-to-diameter (t/D) ratio of the pipe.

The smaller the modulus , the lower the surge pressures; because of this, the designer should generally expect lower calculated surge pressures for GRP pipe than for pipe materials with higher modulus or thicker wall or both.

Changes of flow velocity increase the maximum pressure. The parameter to calculate the theoretical value of the maximum pressure is the wave velocity "c", which depends on the pipe characteristics and flow properties of the fluid.

The value of "c" is given by:

$$c = \sqrt{\frac{K/\rho}{1+\frac{K}{E}\frac{D}{t}}}$$

where:

r = *water density = 1000 N* s^2 / m^4
K = *water bulk modulus = 2200 x* 10^6 *Pa (at 15* ^oC *and up to 10 bar pressure)*
D = *inside diameter of pipe, mm*
E = *hoop modulus of elasticity of the pipe, Pa*
t = *mechanical thickness, mm*

The theoretical value of the maximum/minimum surge pressure is obtained from the following formula:

$\Delta H = \pm c\Delta v/g$

where:

DH = *surge pressure, m*
Dv = *change in liquid velocity, m/s*

If the operation has a sudden change in the flow rate (i.e. pump start-up or shut-down, valve quick closure,.), Δv is equal to the fluid mean velocity.

The following allowance is commonly accepted for GRP pipe (AWWA C 950/95):

$P_w < NP$
$P_w + P_s < 1.4\ NP$

where:

P_w = *working pressure*
P_s = *surge pressure*
NP = *nominal pressure*

This means that the surge pressure tolerated in GRP piping system can exceed by 40% the pressure class.

10. SYSTEM DESIGN

10.1 DESIGN PHILOSOPHY

Rational and experimental methods used in designing GRP systems are followed for *SARPLAST* pipes design. Most of performance limits are determined from long-term strength characteristics. Design factors are used to ensure adequate system over the intended system life of the pipe by providing for unforeseen variations in materials properties and loads.

The structural design procedure involves establishing of the design conditions, selection of the pipe classes and corrisponding pipe properties, selection of installation parameters, and performing pertinent calculations to satisfy the design requirements. The procedure usually requires iterative calculation that can be simplified with the aid of the computer. *Iniziative Industriali* has developed dedicated software for the calculations of stresses, strains and deformations for underground and aboveground applications.

10.2 DESIGN CONDITIONS

Before selecting a *GRP* pipe, the following design conditions should be established:

- Nominal pipe diameter
- Working pressure P_W
- Surge pressure P_S
- Internal vacuum pressure P_V
- Installation conditions: aboveground, underground, subaqueous, ...
- Average service temperature and range

10.3 PIPE PROPERTIES

Preliminary pipe pressure and stiffness classes selection is made on the basis of the design conditions.

Pipe properties necessary for performing calculation include:

- Reinforced wall thickness t and liner thickness t_L, in mm
- Hoop modulus of elasticity, tensile E_H and flexural E in MPa
- Hydrostatic design basis HDB or allowable strain e
- Poisson's ratios ν_{hl}, ν_{lh}

10.4 INTERNAL PRESSURE CLASS

The nominal pressure should be the most severe internal operating pressure that the system will be subjected to under all modes of operation, including starts-up, shut-downs, deflection for undergriund and aboveground installation, etc., throughout the entire life time of the system. As previously described, the Nominal Pressure NP should be:

$P_w \leq NP$ and $P_w + P_s < 1.4\ NP$

The pressure class Pc according to AWWA C950-95 is related to the long term strength, HDB, of the pipe as follows:

On strain basis HDB

$$P_c \leq \left(\frac{HDB}{FS} \frac{2E_H t}{D} \right)$$

where:

FS = *minimum design factor, 1.8*
D = *mean pipe diameter, mm*

The hydrostatic design basis (HDB) for internal pressure class is based on a long-term test performed in accordance with ASTM D2992 Procedure B.

10.5 STIFFNESS CLASSES

The Stiffness of a pipe is defined as the resistance of a pipe to circumferential deflection in response to external loading applied along one diametric plane.

The Stiffness of the pipe S (in N/m^2) is given by the relationship:

$$S = EI/D^3$$

where:

E = *hoop flexural modulus of elasticity, Pa*
I = *moment of inertia of pipe wall calculated as* $I = t^3/12$, *in* mm^3, *with t = pipe wall thickness*
D = *mean pipe diameter, mm,*

10.6 MINIMUM BENDING RADIUS

In many cases it is useful to know the minimum bending radius of a pipe when subjected to bending loads.

The formula applied for the calculation of the minimum allowable bending radius is the following:

$R_m = E_b*D/2/\sigma_b = D/2/\varepsilon$

where:

R_m = minimum allowable bending radius, mm

E_b = bending modulus of elasticity, N/mm^2

D = mean diameter of pipe, mm

σ_b = maximum allowable bending stress, N/mm^2

ε = maximum allowable strain, mm/mm

11. ABOVEGROUND PIPELINE DESIGN

11.1 DESIGN

Above ground installations are usually hung or supported

In nearly all aboveground applications a restrained joint (B/2RLJ, Butt & Strap or Flanged) should be used. Only in case of well supported pipe lines for non-pressure applications an unrestrained system (B/2R, Mechanical Coupling) can be used.

Preliminary pipe pressure and stiffness classes selection is made on the basis of the design requirements as described in the previous section. In particular the stiffness class shall be selected such as the pipe withstand the external pressure conditions as described below.

Piping and its supports are to be designed as to accomplish both pressure and thermal length variation, plus bending loading imposed by supports and spans. Changes of temperature, due to operating conditions or environment, give changes of length and end loading on GRP pipe, which have to be properly manufactured in order to keep values of stress and strain lower than the allowable ones.

11.1.1 External pressure or vacuum

The critical (buckling) pressure P_b (Mpa) is calculated as follows:

$$P_b = \frac{E_H t^3}{4(1-\upsilon_{hl}\upsilon_{lh})R^3} = 24 * \frac{S}{(1-\upsilon_{hl}\upsilon_{lh}) * 10^6}$$

where:

R = *mean pipe radius, mm*
S = *stiffness of the pipe; Pa*

It shall be:

$E_P < P_b * SF$

where:

E_P = *external pressure, MPa*
SF = *safety factor = 2.5*

11.1.2 Thermal expansion in unrestrained pipeline

The expansion Δl of unrestrained pipeline due to temperature variations is determined by the following formula:

$\Delta l = \pm a \Delta t L$

where:

a = *thermal expansion coefficient, 1/ °C*
L = *initial pipeline length, mm*
Δt = $T_d - T_i$, *°C*

where

Td = *design temperature, °C*
Ti = *installation temperature, °C*

11.2 THERMAL END LOADS IN RESTRAINED PIPELINE

The end forces generated by GRP pipes are lower if compared to those generated by metallic piping because of lower longitudinal elasticity modulus of GRP pipes.

The equation for calculating the thermal end load F is the following:

$F = \alpha \, \Delta t E_l A$

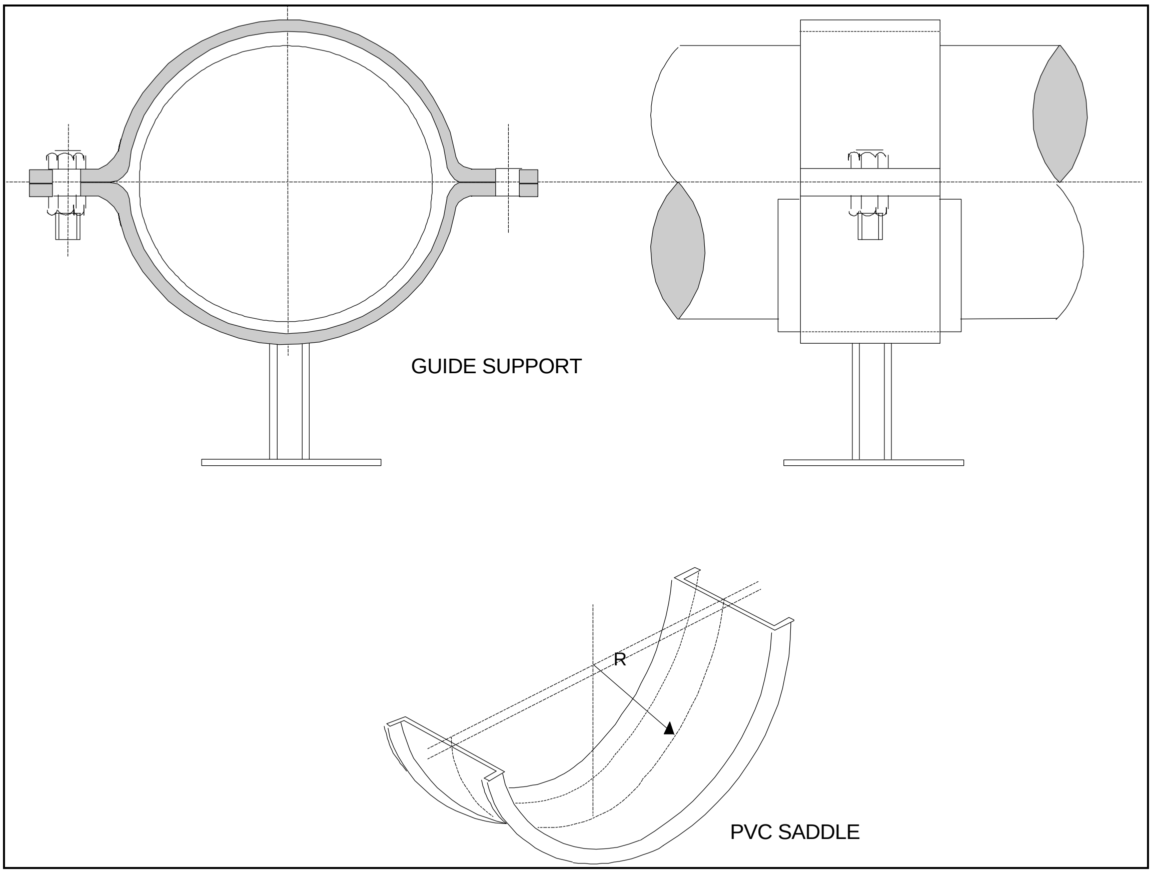
where:

A = *cross section area,* mm^2
E_l = *longitudinal modulus of elasticity, MPa*

11.3 TYPICAL SUPPORTS AND ANCHORS

For the supporting of pipe systems several types of pipe clamps can be used. Line contacts and point loads should be avoided, therefore between pipe and steel collar, a PVC saddle or a protective rubber layer should be provided to minimize abrasion. The PVC saddle is inserted when free axial sliding of the pipe must be permitted (axial guide).

Anchors prevent the pipe axial movement against applied forces and can be installed in both horizontal and vertical directions.



11.4 SUPPORTS SPACING

Pipe span Lsup is defined as the distance between two pipe supports or anchoring devices.

The span length is limited by the following considerations:

1) the maximum axial stress shall not exceed the allowable value;

2) the mid span deflection must be < 1/300 of the span length.

The allowable axial stress value is the allowable axial stress of the pipe less the actual axial stress due to pressure, that is depending on the joining system used (uni-axial or bi-axial stress conditions).

The maximum span has to be evaluated for a **single span length** when the joint cannot withstand flexural loads (B/2R, Mechanical or Flanged) when there is a change in direction of the pipeline, an expansion joint or loop, and there is a valve. In this case the span is the distance LS between two supports placed on a single pipe.

LS can be calculated with the following equations:

a) Based on the allowable axial stress:

$$LS_1 = \sqrt{\frac{8 w_b \sigma_l}{W}}$$

where:

$\sigma_l = \sigma_{all} - \sigma_{ax}$ and the axial stress s_{ax} :

$$\sigma_{ax} = \frac{PD_m}{4t}$$ in case of axial stress (Flanged, etc.)

$$\sigma_{ax} = \frac{PD_m}{8t}$$ in case of uniaxial stress (B/2R, etc.)

LS1 = *maximum span (mm)*
w_b = *section modulus of pipe (mm^3)*
sl = *remaining axial stress, Mpa*
s_{allow}= *allowable axial stress, Mpa*
P = *working pressure, Mpa*
W = *unit weight of the pipe full of water (N/mm)*
Dm = *mean diameter of the pipe (mm)*
t = *minimun wall thickness (mm)*

b) Based on deflection

$$LS_2 = \sqrt[3]{\frac{1}{300} \frac{384}{5} \frac{E_l I_z}{W}}$$

where:

E_l = *axial modulus of pipe (N/mm^2)*
I_Z = *momentum of inertia of pipe (mm^4)*
W = *weight of pipe full of water (N/mm)*

The maximum span LS for a simply supported system is the lower between LS1 and LS2.

The Tab. 11.1 shows the maximum span lengths suggested by *Iniziative Industriali* Technical Department for standard SARPLAST PLASTIWIND pipe made with isophtalic resin having a winding angle of 55°, full of water at a temperature of 40°C with a working pressure equal to 0.8 NP.

Tab. 11.1 Single span lengths LSo (m) @ 40 °C

ND	NP 6	NP 10	NP 16
25	-	-	2.0
50	-	-	2.5
75	-	-	3.0
100	-	-	3.0
125	-	-	3.5
150	-	-	3.5
200	-	-	3.5
250	-	4.0	4.5
300	-	4.0	4.5
350	4.0	4.5	5.0
400	4.0	4.5	5.0
450	4.0	4.5	5.5
500	4.0	4.5	5.5
600	5.0	5.5	6.0
700	5.0	5.5	6.0
800	6.0	6.0	6.0
900	6.0	6.0	6.0
1000	6.0	6.0	6.0
1200	6.0	6.0	6.0

The maximum span has to be evaluated for a **continuous span length** when the joint can transmit flexural loads (Butt & Strap, B/2RLJ). In this case the span is the distance LC between two supports of a pipeline, placed at 0.2 LC from the joint, on the left side of the bell.

LC can be calculated with the following equations:

a) Based on the allowable axial stress:

$$LC1 = \sqrt{\frac{12 w_b \sigma_l}{W}}$$

b) Based on deflection

$$LC2 = 12429 * \sqrt[3]{\frac{E_l I_z}{W}}$$

The maximum span LC for a simply supported system is the lower between LC1 and LC2.

From a comparison between LS and LC it can be found the following:

LC1 = 1.22 LS1 based on allowable axial stress

LC2 = 1.71 LS2 based on allowable deflection

When the specific gravity of the fluid is higher than water specific gravity, the final support span must be reduced as follows:

$Lsup = Lsup_0 * Kj$

where:

Lsup = *final support span*
$Lsup_0$ = *standard support span*
Kj = *specific gravity correction factor*

Specific gravity of fluid	**Correction Factor** *Kj*
kg/m^3	---
1.000	1.00
1.250	0.90
1.500	0.85
1.800	0.80

In case of working temperature higher than 40 °C a coefficient Kt must be used to reduce the axial modulus of the pipe.

In any case, it is suggested to contact the *Iniziative Industriali* Technical Department to identify the appropriate allowable span.

11.5 EXPANSION LOOPS

The allowable activation force for expansion joints depends on both the thermal forces developed in the GRP pipe and the support or guide spacing. In cases of limited motion capability or high activation forces of the expansion joints, loops are used to handle thermal expansion.

Expansion loops are arcs of pipe between two fixed supports that flex to accommodate changes in length. The design method derives from stress developed in a cantilevered beam with a concentrated load at the guided end.

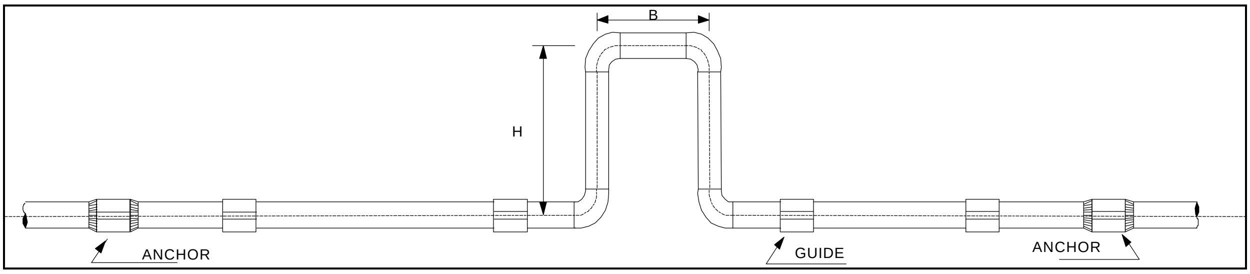
This analysis ignores the flexibility of the bends and of the leg parallel to the line.

$$H = \sqrt{\frac{k \Delta l E_l D_e}{\sigma_i}}$$

where:

H = leg length, mm
k = coefficient = 3 (for a guided cantilevered beam)
Dl = length change for each side, mm
E_l = longitudinal modulus of elasticity, MPa
D_e = external diameter, mm
sl = remaining axial stress, Mpa = s_{allow} - s_p
s_{allow} = allowable axial stress, MPa
s_p = stress due to pressure, MPa

The B length is usually assumed equal 2 times H length.



11.6 DIRECTIONAL CHANGES

In some installations, system directional changes can perform the same function as expansion loops. Stress in the pipe at a given directional change depends on the total change in length to absorb and the distance H to the first secure hanger or guide past the directional change. Supports must prevent lateral movement or pipe buckling.

The calculation of the length required to compensate a given expansion is equal to that used for loops using a k value equal to 1.5 .

$$Lh = \sqrt{\frac{1.5 \Delta l E_l D_e}{\sigma_i}}$$

where:

Lh = *length from direction change to the first support, mm*
Dl = *length change, mm*
E_l = *longitudinal modulus of elasticity, MPa*
D_e = *external diameter, mm*

As previously described in the section concerning the thermal end loads, the lower modulus of GRP pipes reduce the end forces and also the value of H and Lh (leg length and length from direction change) compared to those generated in metallic piping.

12. UNDERGROUND PIPELINE DESIGN

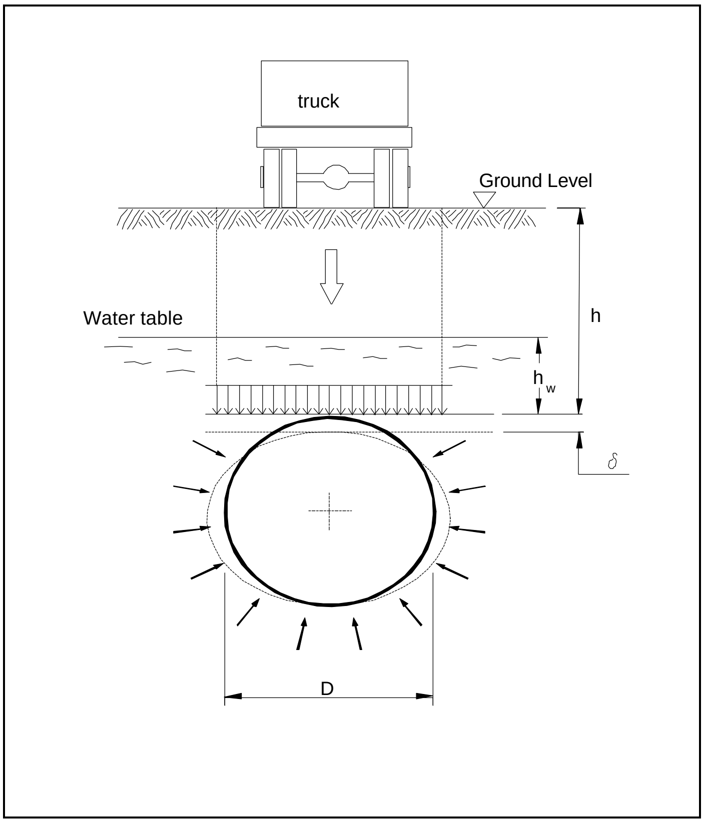
ANSI/AWWA Standard C950-95 and AWWA Manual M45 are the basic references of this guidance to select the appropriate *SARPLAST* pipe for underground installation.

AWWA Manual M45 (First edition 1996) gives the design requirements and criteria for buried fiberglass pressure pipe.

Fiberglass pipes are flexible and can sustain large deformation without any difficulties for the material.

Vertical loads (covering soil, traffic and water table) determine a deflection depending on soil compaction around the pipe and on ring stiffness of the pipe cross section.

The following figure shows the load distribution and mobilization of soil reaction, caused by soil compression in interaction with pipe's flexibility and deformation.



12.1 DESIGN CONDITIONS AND INSTALLATION PARAMETERS

The development of soil and pipe interaction and the resulting deflection of pipe is depending on pipe and soil composition and installation procedure.

The pipe deflection is affected mainly by the following parameters:

- hoop flexural modulus of elasticity
- wall cross section geometry.

Soil condition and installation procedure determine the deflection limitation through the pipe backfilling zone and main criteria are:

- soil composition and material: soil specific weight γ_s, depth of cover (min/max),

- bedding and backfilling of pipe and compaction of soil material.
- vehicular traffic load P
- internal vacuum pressure, P_v

Combination of type and degree of compaction for native and pipe zone soils and trench width will determine the following installation parameters for design calculation:

- Deflection coefficient K_x

- Modulus of soil reaction E'

- Deflection lag factor D_L

12.2 DESIGN REQUIREMENTS

Pipe properties necessary for performing calculation are the same described in Chapter 10.

AWWA Manual M45 recognizes that the pipe design can follow two different procedures based on the stress or on the strain. Iniziative Industriali follows the strain procedure.

The design procedure involves the following steps:

1. Check the working pressure P_w

The working pressure shall not exceed the pressure class of the pipe $P_W \leq P_C$

2. Check the surge pressure P_s

The maximum pressure shall not exceed 1.4 the pressure class of the pipe $Pw + Ps < 1.4Pc$

3. Check ring bending

The maximum allowable long-term ring bending strain brings to the allowable long term vertical deflection.

$$\varepsilon_b = D_f \left(\frac{\Delta y_a}{D}\right)\left(\frac{t_t}{D}\right) \leq \frac{S_b}{FS}$$

where:

D_f = *shape factor, function of pipe stiffness and installation, given by the Table 5.1 of the AWWA Manual M45.On the safety side the following values can be used, depending only on the pipe stiffness (S according to European standard; see below):*

Stiffness [Pa]	1250	2500	5000	10000
D_f	8.0	6.5	5.5	4.5

t_t =*total pipe wall thickness*
D =*pipe diameter (mean)*
Dy_a =*allowable deflection*
S_b =*long term ring bending strain for the pipe*
FS =*design factor, 1.5*

The allowable long term deflection will be:

$$\left(\frac{\Delta y_a}{D}\right) \le \frac{1}{D_f}\frac{S_b}{FS}\left(\frac{D}{t_t}\right)$$

4. Check deflection

The external loads (dead and live) shall not cause a long-term decrease in the vertical diameter higher than 5% or the one allowed by the pipe whichever is the lower:

$$\frac{\Delta y}{D} \le \min\left(5\%, \left(\frac{\Delta y_a}{D}\right)\right) = \left(\frac{\delta}{D}\right)$$

The predicted long-term vertical deflection is calculated as follows:

$$\frac{\Delta y}{D} = \frac{(D_L W_C + W_L)K_x}{0.149\,PS + 0.061E'} \quad or \quad \frac{(D_L W_C + W_L)K_x}{8S + 0.061E'}$$

where:

Δy =*predicted vertical pipe deflection*

D_L =*deflection lag factor [dimensionless]*
After the soil has been placed, it continues to consolidate along the time. The deflection lag factor converts the immediate deflection of the pipe to the deflection of the pipe after many years.
For shallow burial depths with moderate or high degrees of compaction DL =2.0; for dumped or slight degrees of compaction DL =1.5

W_C =*vertical soil load on the pipe [N/m²] =* $g_S \times H$ *(sylos effect is neglected)*

g_s = *specific weight of the soil [N/m³] (19000 - 20000 N/m³)*

H = *burial depth to the top of pipe [m]*

W_L =*live load on pipe [N/m²] =* $(P \times I_f) / (L_1 \times L_2)$

P = *wheel load [N] = 16000 lbs for HS-20 truck (72570 N)*

I_f = *impact factor [dimensionless]*

= 1.1 for 0.6 m< H < 0.9 m (2 ft < H < 3 ft)
= 1 for H ≥ 0.9 m (H ≥ 3 ft)

L_1 = *load width parallel to direction of travel*
= 0.253 + 1.75 H

L_2 = *load width perpendicular to direction of travel*
= 0.51 + 1.75 H   *for 0.6 m < H < 0.76 m*
= (13.31 + 1.75 H) / 8   *for H ≥ 0.76 m*

K_x *= deflection coefficient – the deflection coefficient reflects the degree of support provided by the soil at the bottom of the pipe and over which the bottom reaction is distributed). Values of* K_x *are based on the description of the type of installation*
= 0.083   *for uniform shaped bottom support*
= 0.1   *for direct bury*

PS *=Pipe Stiffness as defined by ASTM and AWWA standards*

S *=Stiffness as defined by BS 5480 or ISO standards*

For both American and European standards the pipe stiffness (*PS*) and the stiffness (*S*) are measured with a parallel plate loading test. The relation between the two parameters is:

$$PS = \frac{1}{0.149}\frac{EI}{r^3} \qquad\qquad S = \frac{EI}{D^3}$$

$$0.149\,PS = \frac{EI}{r^3} \qquad\qquad 8S = 8\frac{EI}{D^3} = \frac{EI}{r^3}$$

$$\therefore \quad 0.149\,PS = 8S$$

where:

E *=pipe ring modulus of elasticity (MPa)*

I *=moment of inertia for unit length of pipe wall for ring bending* (mm^4/mm)

The product EI is also called stiffness factor per unit of circumference. The stiffness factor EI is determined from the parallel plate loading test with the equation EI = 0.149 r^3 ($F/\Delta y$) where *F* is the force per unit length and Δy the vertical pipe deflection. The test is carried out for a deflection equal to 5% of the diameter.

E' *= composite modulus of soil reaction [MPa]:*

E' *= Sc E'b*

where

E'_b *=modulus of soil reaction for the pipe zone embedment, from the following table:*

Modulus of soil reaction E'$_b$ for the pipe zone embedment [MPa] – M45 Table 5-5					
Soil Stiffness Category	Maximum Content of Fine-grained Soil	Degree of compaction			
		Dumped	Slight <85% Proctor	Moderate 85-95% Proctor	High >95% Proctor
SC1	5%	6.9	20.7	20.7	20.7
SC2	12%	1.4	6.9	13.8	20.7
SC3 a	50%	.69	2.8	6.9	13.8
SC3 b	70%	.69	2.8	6.9	13.8
SC4	100%	.34	1.4	2.8	6.9

SC1, SC2 and SC3a are defined as coarse grained soils with fines.

SC3b and SC4 are fine grained soils with medium to no plasticity.

Highly compressible fine grained soils (SC5) should not be used for pipe zone embedment.

SC3a and SC3b give the same modulus but the compaction effort will be different.

S_c = *soil support combining factor, depending on the ratios between (a) trench width and pipe diameter and (b) modulus of soil reaction of native and embedment soils, from the following table:*

	B_d/D					
E_n'/E_b'	1.50	2.00	2.50	3.00	4.00	5.00
0.10	0.15	0.30	0.60	0.80	0.90	1.00
0.20	0.30	0.45	0.70	0.85	0.92	1.00
0.40	0.50	0.60	0.80	0.90	0.95	1.00
0.60	0.70	0.80	0.90	0.95	1.00	1.00
0.80	0.85	0.90	0.95	0.98	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.50	1.30	1.15	1.10	1.05	1.00	1.00
2.00	1.50	1.30	1.15	1.10	1.05	1.00
3.00	1.75	1.45	1.30	1.20	1.08	1.00
5.00	2.00	1.60	1.40	1.25	1.10	1.00

B'_d =*trench width (at pipe springline)*

E'_n =*modulus of soil reaction of native soil at pipe axis, according to Table 5-6 of AWWA M45:*

Granular Soils		*Cohesive Soils*		*Native Soil Modulus (MPa)*
Blows/ft	*Description*	q_u *(Tons/sqf)*	*Description*	
0-1	*very, very loose*	*0-0.125*	*very, very soft*	*0.34*
1-2	*very loose*	*0.125-0.25*	*very soft*	*1.38*
2-4		*0.25-0.50*	*soft*	*4.83*
4-8	*loose*	*0.50-1.0*	*medium*	*10.3*
8-15	*slightly compact*	*1.0-2.0*	*stiff*	*20.7*
15-30	*compact*	*2.0-4.0*	*very stiff*	*34.5*
30-50	*dense*	*4.0-6.0*	*hard*	*69.0*
>50	*very dense*	*>6.0*	*very hard*	*138*

In most of the situation a soil support combining factor SC=1 is used. Only when there are a native soil very bad or a very hard loading condition, a more careful calculation has to be made.

Special cases of native soils are:

- trench in rock: E'_n = 345 MPa
- geotextiles: the native soil modulus may be increased by 1.5x
- permanent solid sheeting: S_c = 1 with any native soil
- cement stabilized sand (1 sack per ton): E'_n = 170 MPa when hardened, as simple compacted sand before hardening

5. <u>Check combined loading</u>

In case of deflection and internal pressure both the following equations shall be verified:

$$\frac{\varepsilon_{pr}}{HDB} \leq \frac{1-\left(\frac{\varepsilon_b r_c}{S_b}\right)}{FS_{pr}}$$

$$\frac{\varepsilon_b r_c}{S_b} = \frac{1-\left(\frac{\varepsilon_{pr}}{HDB}\right)}{FS_b}$$

where :

r_c = *rerounding coefficent*

= *1 - P_w/3 ($P_w \leq 3\ N/mm^2$)*

e_{pr} = *strain due to internal working pressure*

$$= \frac{P_w D}{2E_H t}$$

e_b = *bending strain due to maximum allowed deflection*

$$= D_f\left(\frac{\delta d}{D}\right)\left(\frac{t_t}{D}\right)$$

FS_b = *bending design factor, 1.5*

Fs_{pr} = *pressure design factor, 1.8*

6. Check buckling

The sum of external loads shall be equal to or less than the allowable buckling pressure. The allowable buckling pressure q_a is determined by the equation:

$$q_a = \left(\frac{1}{FS}\right)\sqrt{32 R_w B' E' S}$$

where :

FS = *design factor, 2.5*

B' = *empirical coefficient of elastic support,*

$= \dfrac{1}{1+4e^{-0.213h}}$ *(for h in meters)*

R_w = *water buoyancy factor,*

= *1 - 0.33* (h_w/h) *for* $0 \le h_w \le h$

h_w = *height of water above top of pipe, m*

h = *height of soil above top of pipe, m*

S = *Pipe Stiffness Class*

The above equation is valid for the following conditions:

- without internal vacuum $0.6\ m \le h \le 24.4\ m$
- with internal vacuum $1.2\ m \le h \le 24.4\ m$

Where internal vacuum occurs with $0.6\ m \le h \le 1.2\ m$, q_a is determined by the von Mises formula:

$$q_a = \left(\frac{2Et}{D\left(n^2-1\right)\left(1+K\right)^2}\right) + \left(n^2 - 1 + \frac{2n^2 - 1 - \upsilon_{hl}}{1+K}\right)\left(8S\frac{1}{\left(1-\upsilon_{hl}\upsilon_{lh}\right)}\right)$$

where :

n = *number of lobes formed at buckling,* ≥ 2

K = $(2nL/pD)^2$

L = *distance between ring stiffeners; for solid-wall (not ribbed) pipes, L shall be the distance between joints (such as bells, couplings, flanges, etc.).*

Satisfaction of the buckling requirement is assured for normal pipe installations by the following equation:

$\gamma_w h_w + R_w(W_c) + P_v \leq q_a$

where:

g_w = *specific weight of water*

P_V = *internal vacuum pressure*

If live load are considered, the buckling requirement is assured by:

$$\gamma_w h_w + R_W(W_c) + W_L \leq q_a$$

Simultaneous application of live-load and internal-vacuum transients does not need to be normally considered.

The possible presence of water table above top of pipe is taken into consideration in R_W factor of the buckling formula.

12.3 BUOYANCY

If water table is above top of the pipe a check against buoyancy with the pipe empty of water has to be done.

The load for unit length due to weight of soil has to be higher than the buoyancy force (F_{up}).

$F_{up} = SF(W_p + W_s)$

where:

F_{up} = *uplift force (buoyancy)*

=$p/4\ D^2_e\ g_w$

W_s = *soil weight above the pipe*

=$D_e\ g_s\ R_w\ H$

W_p = *pipe weight*

D_e = *pipe external diameter*

g_s = *specific weight of dry soil*

R_w = *water buoyancy factor* = $1 - 0.33\ (h_w/H)$

h_w = *height of water above top of pipe*

H = *height of soil above top of pipe*

g_w = *specific weight of water*

SF = *safety factor, 1.5*

13. INSTALLATION AND JOINING METHODS

For the installation and adjusting of pipe systems in the field the following jointing methods, as described in paragraph 4, are available:

- Double O-ring Bell and Spigot Joint
- Double O-ring Bell and Spigot with locking key joint
- Mechanical coupling
- Butt and strap joint
- Flanged Joint

The procedures to assemble the various type of joint are described in *Iniziative Industriali* Technical Specifications.

For the installations of pipes and fittings, the following methods can be chosen:

a) Pipeline system can be made by using the standard component. In this case all the joints and adjustments should be made in the field. For each connections the butt and strap joining system shall be used. As the adjustments of the pipeline system will be made in the pipe it is advised to use butt and strap joint for fittings to realize a quicker and cheaper installation.

b) Pipeline system can be installed by using prefabricated system parts (spools), composed with pipes, elbows, reducers...and supplied with different type of joint. The main advantages of this method are the following: quick and easy mounting, narrow tolerances, less field joint, lower installation costs.

14. ABOVE GROUND INSTALLATION

Above ground installations can be roughly divided into two categories:

a) lines which laid directly on the surface of the ground

b) lines which are hung or supported as in a typical plant

In case a) it is anyway advisable to support the pipe by means of wooden or concrete sleepers, in order to avoid pipe damage by stones and other sharp object.

In nearly all aboveground applications tensile resistant couplings should be used. Only in case of well supported pipe lines for non-pressure applications a non-tensile resistant system can be used.

Horizontal pipe should be supported at intervals suggested by the support spacing data.

For the supporting of pipe systems several types of pipe clips can be used. Line contacts and point loads should be avoided, therefore between pipe and steel collar, a PVC saddle or a protective rubber layer should be provided to minimize abrasion. The PVC saddle is inserted when free axial sliding of the pipe must be permitted (axial guide). The width of the clamp should be in accordance with ASA or equivalent.

The clips must fit firmly but must not apply excessive force to the pipe wall. This could result in deformations and excessive wall stresses. The pipe must be allowed to expand within its clamps.

Heavy equipment (valves etc.) have to be supported independently from the pipe to avoid overloading in both horizontal and vertical directions.

Excessive loading in vertical runs are to be avoided.

Changes of temperature, due to operating conditions or ambient, give changes of length and end loading on GRP pipe, which have to be properly manufactured in order to keep values of stress and strain lower than the allowable ones. In case of long pipeline or excessive changes of temperature, expansion loops or expansion joints will be necessary.

An anchor must positively restrain the movement of the pipe against all applied forces. Anchors can be installed in both horizontal and vertical directions.

Pipe anchors divide a pipe system into sections and must be attached to structural material capable of withstanding any applied forces. In some cases pumps, tanks and other similar equipment function as anchors. Additional anchors are usually located at valves, changes in direction of piping and major branch connections.

When applying unrestrained joints or mechanical couplers, pipe lines must be anchored at each change of direction.

Anyway the correct location of anchor points shall be settled after a detailed stress analysis.

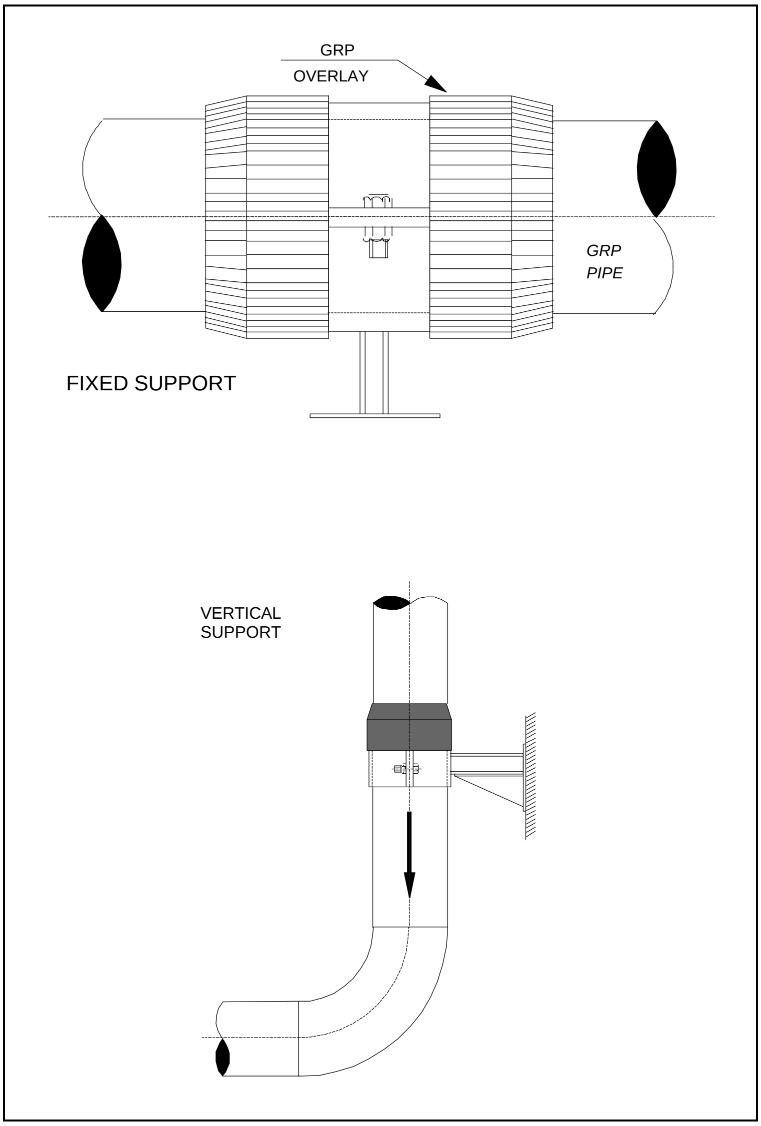
For securing clamp it is suggested to apply a GRP lamination on each side of the clamp. If the movement of the pipe shall be restrained only in one direction, it is sufficient to apply just one overlay in the opposite position.

Sideways movement is to be prevented by clamping.

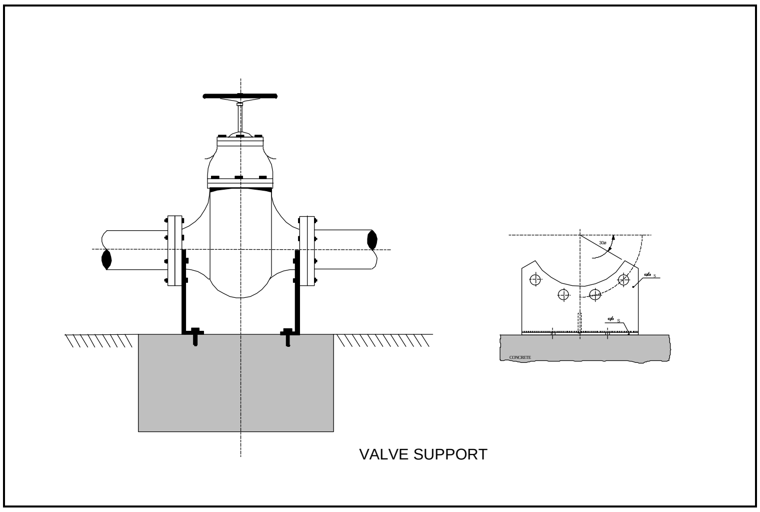
When installing Double O-Ring Lock Joint, these must be fully stretched in order to prevent movement of pipe sections and overloading at points of changes in direction such as bends and tees. It is preferable to apply mechanical stretch but stretching can also be done by pressurising the main line (0.8 x Working Pressure). The results can be observed by inspection of the position of the locking strip through the insert hole. Stretching should be applied before installing branch connections.

Should connections be necessary with machinery or bodies subject to vibrations, such as pumps or other equipment, it is a good engineering practice to avoid a direct link with such systems, because vibrations induce stresses on GRP pipe, which may prevail over the allowable value. A severe condition of vibration occurs when the generating frequency is equal or near the natural frequency of the pipeline. An usual method to avoid vibrations is to install a flexible joint between the source of vibration and the pipe.

SARPLAST GRP pipe exposed to sunlight is not subject to resin degradation, due to ultraviolet radiation, because pipe contains, through the whole wall thickness, inhibitors which prevent said degradation.



GRP
OVERLAY
GRP
PIPE
FIXED SUPPORT
VERTICAL
SUPPORT



VALVE SUPPORT

15. UNDERGROUND INSTALLATION

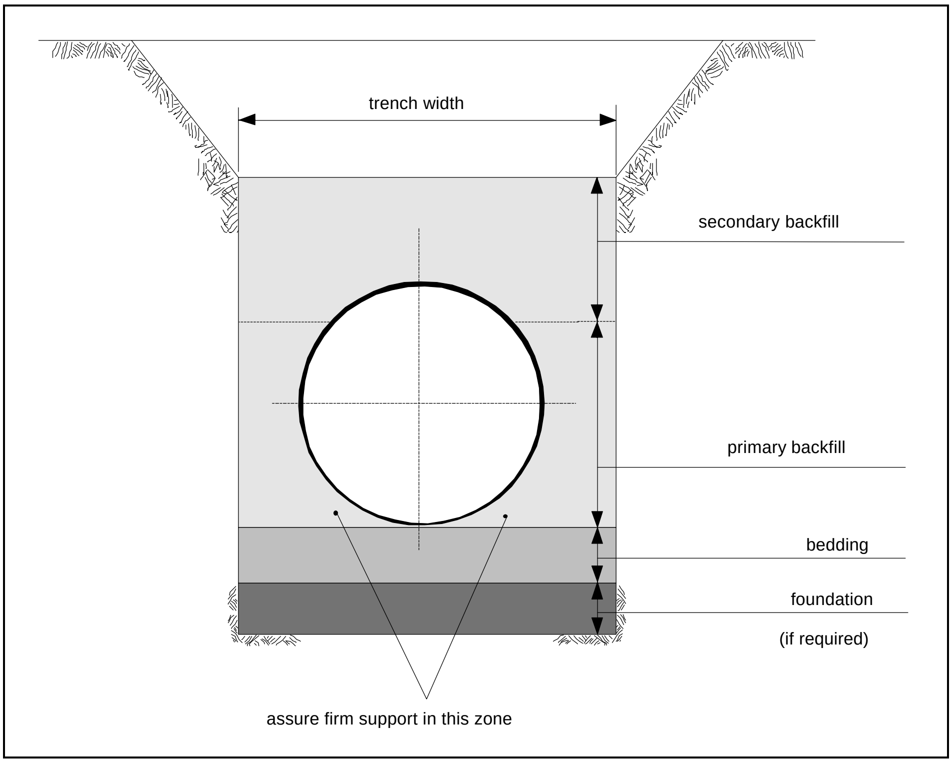
15.1 SOIL - PIPE SYSTEM

The external loads (soil and traffic) above a GRP buried pipe cause a decrease in the vertical diameter and an increase in the horizontal diameter (deflection), that is indicative of strain (stress) levels in the pipe wall.

The horizontal movement develops a passive soil resistance that enhances pipe support.

The amount of deflection depends on soil load, live load, native soil characteristics, pipe backfill material, trench width, haunching and pipe stiffness.

Buried fiberglass pipes generally accommodate 4-5% long term deformation without structural damage. Proper selection of pipe stiffness class and corresponding installation type helps to maintain pipe deflection within acceptable levels.



15.2 CLASSIFICATION OF NATIVE SOILS

Native soils according to AWWA 950/95 are classified in 4 soil stiffness category. The soil groups depend both on soil types (classification) and soil density, which together determine the soil modulus. The symbols GW, GP, SW, SP, GM, GC, SM, SC, ML, CL etc.. are in accordance to ASTM - D2488.

Soil stiffness category 1 (SC1)

Crushed rock and gravel with <15% sand and 5% fines.

SC1 materials provide maximum pipe support for a given density due to low contents of sand and fines. With minimum effort these material can be installed at relatively high soil stiffnesses over a wide range of moisture contents. In addition, the high permeability of SC1 materials may aid in the control of water and are often desirable for embedment in rock cuts where water is frequently encountered. However, when groundwater flow is anticipated, consideration should be given to the potential for migration of fines from adjacent materials into open-graded SC1 materials.

Soil stiffness category 2 (SC2)

Coarse grained soils with little or no fines (GW, GP, SW, SP) or any dual symbol soils or borderline soils beginning with one of these designations such as GW-GC containing 12% of fines or less.

SC2 materials, when compacted, provide a relatively high level of pipe support; however, open-graded groups may allow migration and the sizes should be checked for compatibility with adjacent material.

Soil stiffness category 3 (SC3)

Coarse grained soils with fines (GM, GC, SM, SC) or any dual symbol soils or borderline soils beginning with one of these designations with more than 12% fines; and ML, CL, or borderline soils beginning with one of these designations, such as ML/CL, with 30% or more coarse grained particles.

SC3 materials provide less support for a given density than SC1 and SC2 materials. Higher levels of compactive effort are required and moisture content must be controlled. These materials provide reasonable levels of pipe support once proper density is achieved.

Soil stiffness category 4 (SC4)

Fine grained soils with medium to no plasticity (ML, CL) or borderline soil beginning with one of these designations, such as ML/MH with less than 30% coarse grained particles.

SC4 materials require a geotechnical evaluation prior to use. The moisture content must be near optimum to minimize compactive effort and achieve the required density. When properly placed and compacted, SC4 materials can provide reasonable levels of pipe support; however, high energy level vibratory compactors and tampers. do not use where water conditions in the trench prevent proper placement and compaction.

15.3 PIPE BURIAL

Excavating the trench

On most construction sites it will be desirable to keep excavation, pipe installation and backfilling close together to minimize logistics problems and to reduce supervision costs.

Trench construction will vary according to the types of soil encountered (stable or unstable). In any case the trench bottom shall be flat and continuous.

Stable trench walls or rock trench

Trench wall usually can be made vertical from the bed to the top of the pipe without the use of shoring or sheet piling.

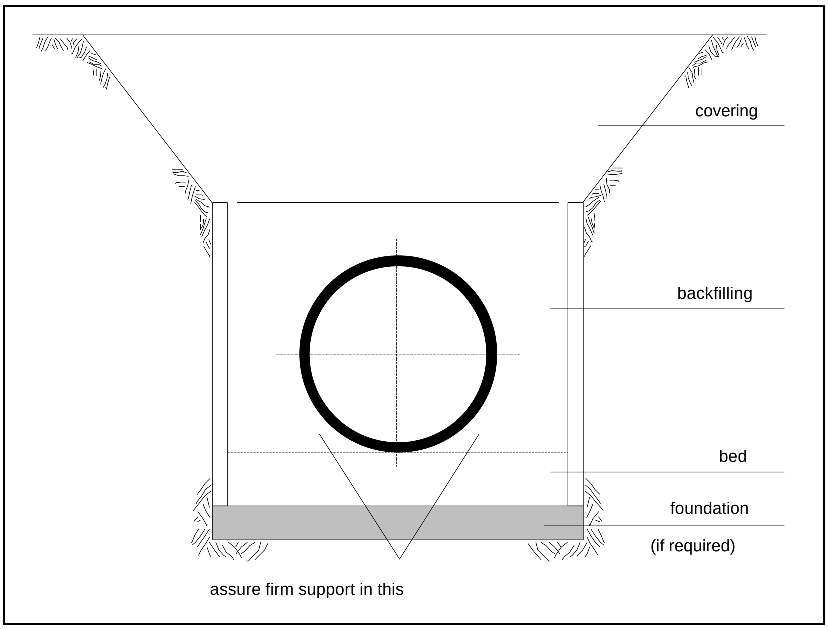
Unstable trench walls and bottom

The trench will be excavated with vertical wall providing sheet shoring, installation method 1or with the natural slope of the soil, installation method 2.

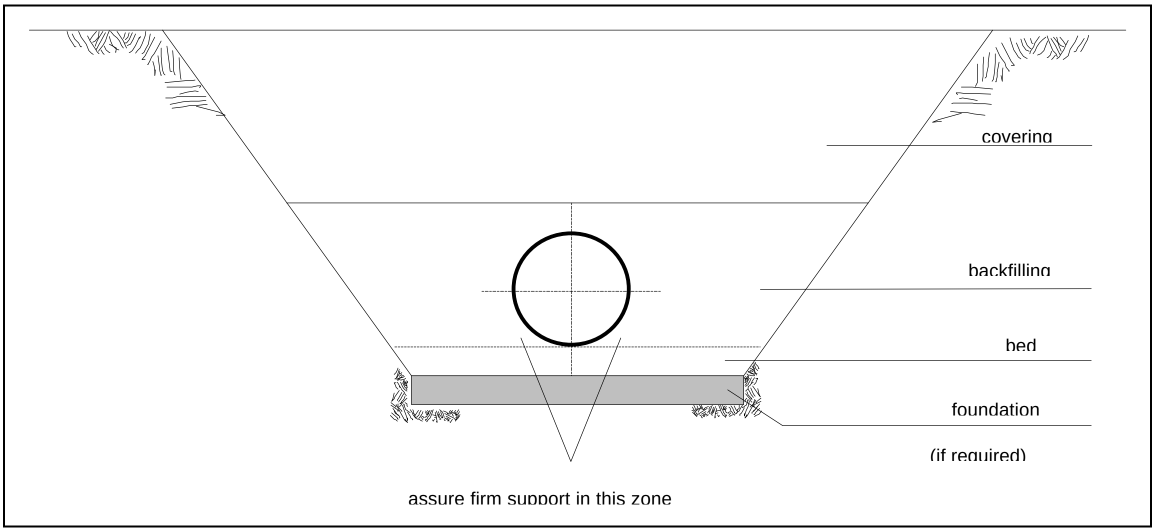
The foundation shown is required when the trench bottom is unstable, i.e. made up of soils whose displacement, due to variation in stress or moisture content, is very high. Depending on the conditions of the unstable trench bottom, the installation contractor may require different types of foundations such as :

- stabilization of the bottom material, by removing it for a minimum depth of 200 mm and replacing it with stabilized gravel or sand, into which the unstable soil will not penetrate (ground capacity from 0.7 to 0.9 kg/cm^2);
- concrete material with a minimum depth of 150 mm (ground capacity from 0.5 to 0.7 kg/cm^2);

- piles capped by a concrete material (ground capacity from 0.5 to 0.7 kg/cm^2). The above instruction must be as strictly followed as larger is the pipe diameter.



Installation method 1



Installation method 2

Granular soil trench

The trench walls shall be at the natural slope of the native granular material. Pipe shall be installed as shown in the figure relative to unstable trench, installation method 2.

Soft soil trench

When the native is composed by highly plastic substances, very compressible, with a water content percentage on the dry soil weight exceeding 50%, as soft clays, very melted mud, etc., the granular soil used for the laying bed and the backfilling can be absorbed by the native soil. In this case, it is suitable to cover the bed and the walls with a fabric non-fabric (geotextile), which has the function of separating the layers to prevent that the materials composing the bed and the backfilling from being mixed or buried.

Trench width

The trench width shall be such as to guarantee the minimum distance pipe/trench wall allowing backfilling compaction, according to the type of material used and the compacting method. Furthermore, in case of installation of soils not able to grant the side support requested by the project, the trench will be widened, according to the designer's prescriptions, in order to stabilize the soil.

Suggested value for the trench width are as follows:

L= DN + 400 mm

L= DN + 600 mm

L= DN + 800 mm

The depth of the trench must be such as to have the bedding of the dimensions foreseen in the next paragraphs. If the soil is not able to give the vertical support requested by the project, the trench will be deepened of 20cm or more, according to the prescriptions given by the designer, in order to obtain a more stabilized soil.

Moreover, should butt and strap joints be executed within the trench, it must be widened by 2 meters for a length of two meters in the joining area, in order to allow proper operations.

At the above locations the trench bottom shall be adequately lowered. These joint housings will be filled during backfilling

Trench excavation below water table

Where an unstable soil condition is encountered which is caused by water table, the bottom of the trench must be stabilized before laying the pipes.

This can usually be accomplished by lowering the water table about 30 cm below grade pipe by means of pumps and stabilizing the bottom as already described.

To minimize the dewatering, only enough trench should be opened to place one or two lengths of pipe and then backfill.

Bedding

The bedding shall be minimum 150 mm thick and shall provide the pipe with an uniform and continuous support over its entire length.

The bedding surface shall be even and recesses shall be left corresponding to pipe joints. These receptances shall be backfilled after pipe installation and joining.

We recommends the use of pea gravel, or crushed stone or sand as bedding material, with a fine content not exceeding 12%. With fines we mean materials passing through the ASTM 200 sieve. The maximum dimensions of the bed materials diameter should not be greater than 20mm.

The bed must be compacted until reaching 70% of its maximum density, before the pipe installation (90% Proctor Standard).

Backfilling

Backfilling material will be the same as used for bedding (maximum lime content 10% and maximum particle size 18 mm).

Backfilling is ideally divided in two areas : primary backfilling which vertically extends from the lower generatrix of the pipe as far as 70% of the diameter and secondary backfilling, extending as far as 15 cm above the upper generatrix of the pipe.

Backfilling shall be placed in singly compacted layers 200-250 mm high up to 70% of pipe diameter and 300 mm high up to the top.

Backfilling up to the ground level with native material has to be completed.

Compaction can be made by using an impulsive compactor or any other suitable equipment.

Please address the Technical Office for prescriptions relevant to the compaction ratio and the depth of the bed.

15.4 PIPES INSTALLATION

To install the pipes, the following procedure can be used, in accordance with the type of joint and the pipe diameter:

a) for any type of joint and diameters: lay and align the pipe bars on the previously prepared bed, and perform junctions inside the trench.

b) for pipes which joints guarantee the axial continuity:

- lay on the bed two or three bars, previously joined outside the trench, so as to reduce the number of junctions to be performed inside the trench.
- align and join the pipe bars by the side of the trench or above it, using ties; let the already joined pipeline down the trench, using more hoisting equipment and taking care not to cause excessive deformations; this method can be used for small diameters only.

In case of bell/spigot or socket joints with o-rings, please verify that angles exceeding those allowed have not been given.

15.5 TYPICAL COMPACTION METHODS

The following compacting suggestions will enable to achieve the maximum practical material density. Excessive compaction or compaction with inappropriate equipment can result in pipe deformation or pipe lifting off the bedding. Care must be used when compacting the pipe zone backfill with frequent checks of pipe shape.

Coarse grained soils - 5% fines. For coarse grained soils with less than 5% fines, the maximum density results from compacting, saturation and vibration. Further to the use of internal vibrators, heights of successive lifts of backfill must be limited to the penetrating depth of the vibrator. The backfill is placed in lifts of 0.15 to 0.3 m. Pipeline flotation has to be avoided when saturating the pipe zone backfill area. Water jetting will erode side support and few experts recommend it. Placing backfill over the pipe must be avoided, while the pipe zone material is saturated. That would load the pipe before the proper support can develop.

Coarse grained soils - 5 - 12% fines. Compacting of coarse grained soils containing between 5 and 12% fines, is carried out such as by tamping or saturation and vibration. The method used should result in the maximum density of the backfill.

Coarse grained soils - > 12% fines. Coarse grained soils containing more than 12% fines, compact best by mechanical tamping in lifts of 0.1 to 0.15 m. In particular for fined grained

soils, the soil modulus (passive soil resistance) is density sensitive and a greater compact effort will be required to obtain the necessary Proctor density dictated by design.

Compaction and Installation. Quality Control

Deflection checks must be carried out when the first installed pipes are backfilled to grade. Further periodical checks must be done throughout the entire project. Where practical, measurement has to be taken of the in-place density of the compacted primary pipe zone material to ensure compliance with the design assumptions.

15.6 RIGID CONNECTIONS IN CONCRETE ENCASEMENT

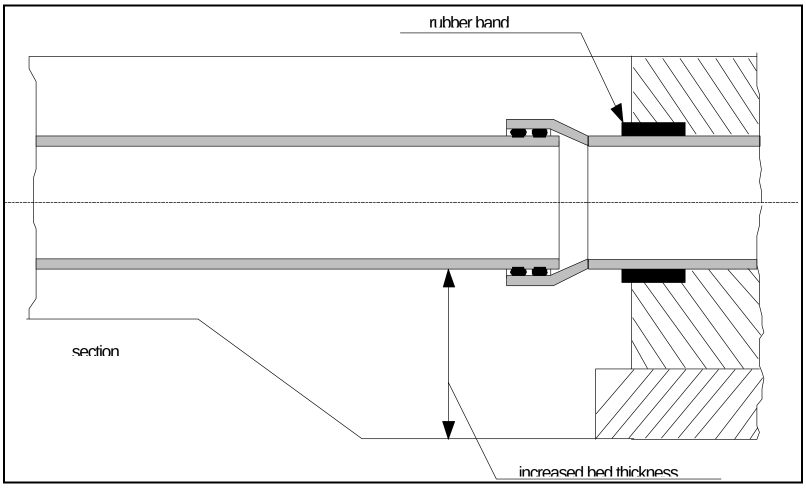
When a pipe passes through a concrete wall, a band of rubber is wrapped (100 - 200 mm wide and 10-20 mm thick depending on the pipe diameter) around the pipe in the area of entry into the concrete structure.

In addition, at this point it is necessary to achieve the following conditions:

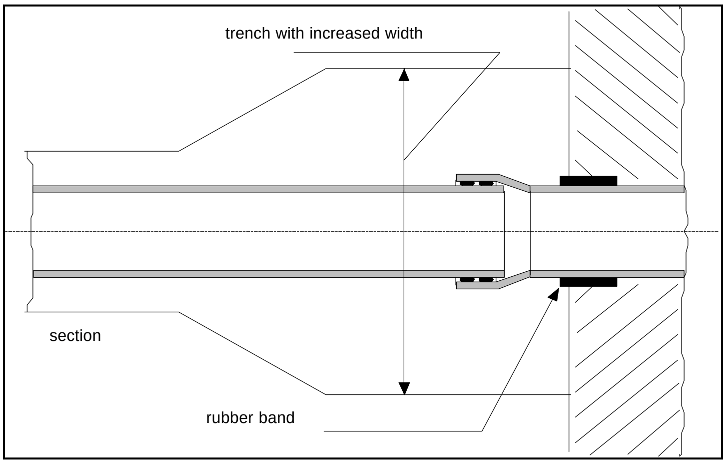
a) Bed minimum depth not less than one pipe diameter for a length not less than two pipe diameters.

b) Trench minimum width three pipes diameters for a length not less than 3 pipes diameter

The following designs describe the section and the plan of the connection with concrete wall.



SECTION



PLAN

15.7 ANCHOR BLOCKS

15.7.1 Design

In case of buried pipes with unrestrained (B/2R or Mechanical Coupling) it is necessary to foresee suitable concrete anchor blocks on elbows, tees, reducers, blind flanges etc. Such anchor blocks are designed in order to withstand the force exerted by the buried fittings.

The use of restrained joints on a certain distance from an elbow or a tee can offer a better solution. In this case it is necessary to evaluate the theoretical anchor length $L_{AN.}$

$$L_{AN} = \frac{ID * P_D}{4(ID + t)F_f}$$

where:

ID =*internal diameter, mm*
P_D = *design pressure, Mpa*
t = *thickness, mm*
F_t = *friction force between pipe and soil, N/mm^2 (0.001÷0.003 N/mm2 for silty clays and wet soils, 0.003÷0.01 for layey sands and sandy soils)*

The force exerted by typical buried fittings are the following:

Elbows

Force acts in the direction of the bisecting line of the elbow.

$F = 2\ P\ A\ \sin(\beta/2)$

where:
P = *test pressure, N/mm^2*
A = *flow area, mm^2*
ß = *deviation angle*

Particular points

Force acts along the flow axis (entering at the particular point)

$F = P\ (A - A_1)$

where:
A = *Section of larger diameter*
A_1 = *Section of lower diameter for reduction (0 in case of tees or blind flange)*

15.7.2 Execution

Anchor blocks can be realized in three ways:

1. gravity
2. reaction
3. mixed

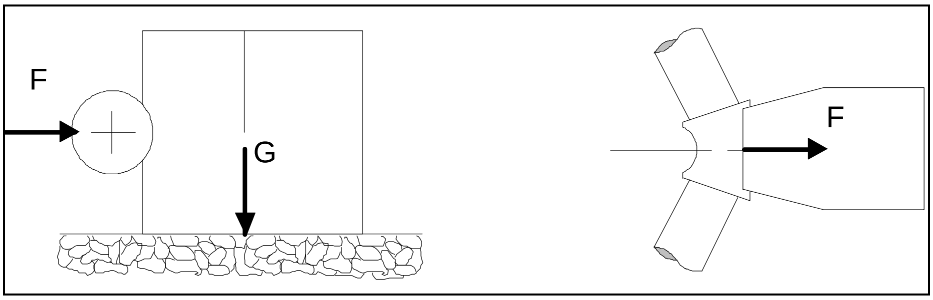
NOTE: Anchor blocks shall never cast the section of the pipe, but they shall be shaped in order to allow the deflection of the pipe under the ground load. A rubber stripe (10-30 mm thick and 150-200 mm long) shall be placed between pipe and concrete at the exit of pipe from the anchor blocks.

1. Gravity anchor blocks

Gravity anchor blocks react only by friction with the soil plane; they will be placed when the soil conditions ensure only friction forces. Anchor blocks shall be made in such a way that their own weight could oppose against the force due to the pressure.

Water table shall be taken into consideration since it reduces the weight of the concrete block.

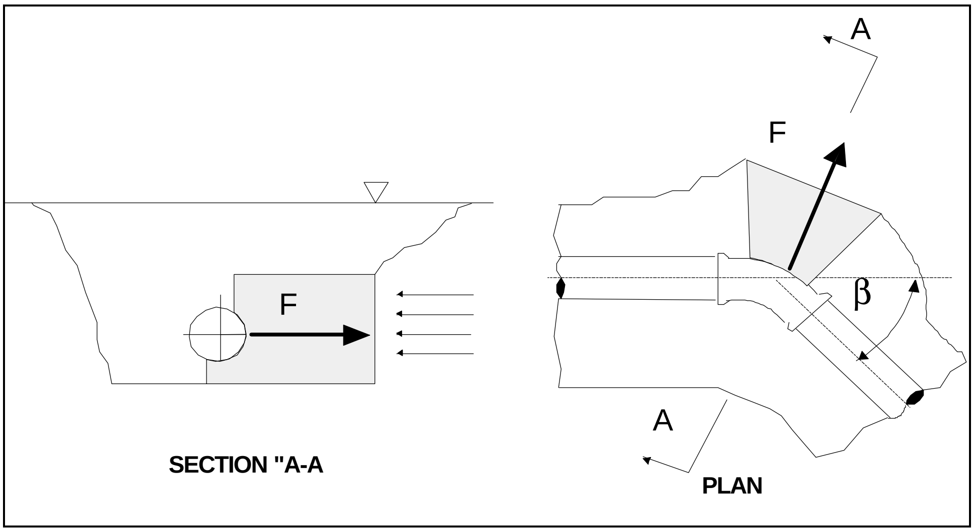
A proper friction coefficient concrete/soil shall be selected in accordance with soil type and conditions.



2. Reaction anchor blocks

Reaction anchor blocks shall be made when soil is provided with stability characteristics (rocky ground, compact and firm soil). In particular it is required an adequate deep of covering not lower than 1 m.

Such anchor blocks work through the passive reaction of the soil; to this purpose it must be cast against a vertical wall of undisturbed soil.



3. Reaction-gravity anchor blocks

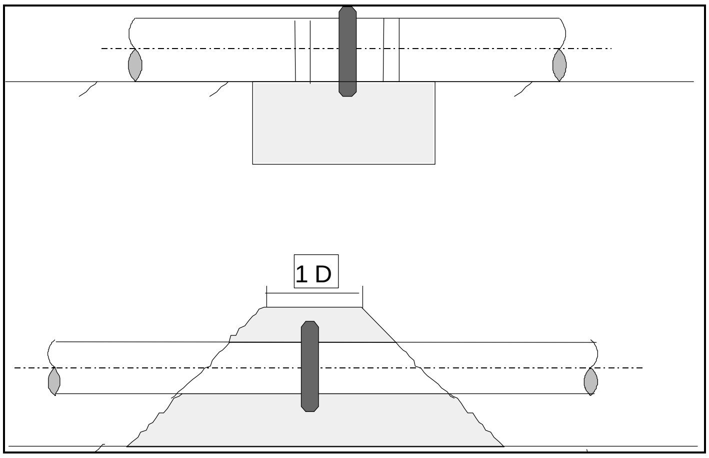
Reaction-gravity anchor blocks shall be placed in case of mixed type of soil (partially stable soil) and when it is possible to exploit the characteristics both of gravity and reaction anchor blocks.

NOTE: For each kind of anchor block, care will be exercised in compacting the surrounding ground and in stabilizing the below ground, if necessary.

15.7.3 Line Anchor Blocks

Line anchor blocks are used to control the axial movements of buried pipelines with flexible joints (bell and spigot or sleeve). Such movements might be caused by pressure variations or by thermal gradients. Anchor blocks can be placed under the pipe and connected to the same by means of nylon strips.

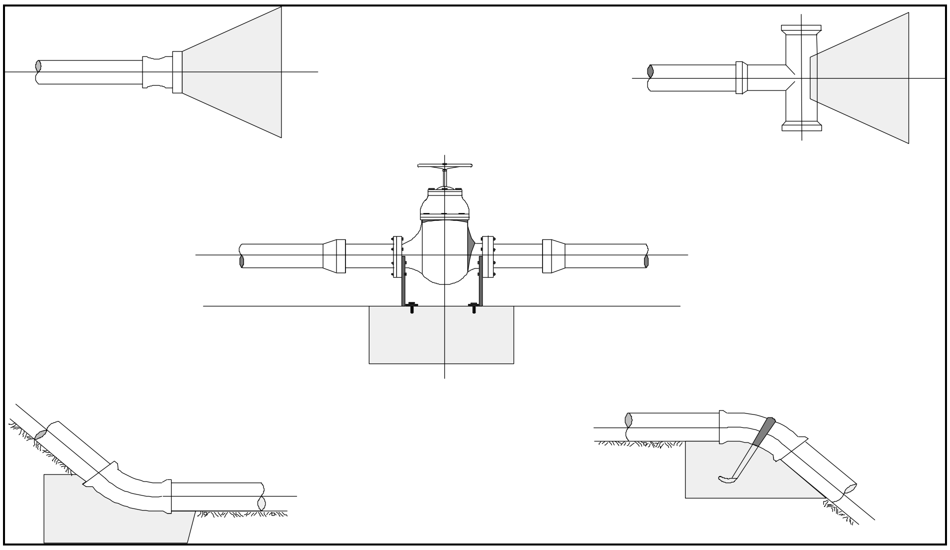
As alternative anchor blocks can be made with lean concrete (50-70 kg/m3), for a suitable length, leaving the lean concrete flow according to its natural friction angle; in both cases pipe shall have a rib in GRP (25 mm thick, 150 mm large).



15.7.4 Typical anchor blocks

Some typical anchor blocks are shown herebelow. They can be used during the erection of buried pipeline (altimetrical elbows, tees, blind flanges, etc.).

Valves shall be always blocked in order to discharge to soil the stress due to operation movements and thrusts when they are closed.



15.7.5 Thrust blocks calculation

In order to calculate concrete thrust blocks the following soil parameters must be taken into consideration:

a. internal friction angle

b. cohesion

c. specific weight

d. friction coefficient of concrete/soil

e. passive soil reaction

Types of soil	Internal friction angle (Φ)	Cohesion (c) [Pa]	Specific weight [N/m3]	Friction coefficient concrete/soil
wet soils, silty clays, organic soils	20° 25°	10000	18000	0.30
sandy soils, clayey sands, sand	30° 35°	5000 0	17000	0.50
dry soils: gravel, crushed stone	40°	0	16000	0.70

The calculation shall follow the steps

A. Calculation of Thrust F [N] (See 15.7.1)

B. Calculation of the passive soil reaction Ts [N]

The passive soil reaction against the concrete block is:

$$T_s = 0.5 g_s \left(H_1^2 - H_2^2\right) B tg^2 (45 + \Phi/2) + 2c\left(H_1 - H_2\right) B \sqrt{tg^2 (45 + \Phi/2)}$$

where

g_s = *soil specific weight, N/m³*
T_S = *soil reaction, N*
H_1 = *distance from ground level to concrete block base, m*
H_2 = *distance from ground level to concrete block top, m*
B = *width of concrete block in contact with soil, m*

C. Calculation of the friction force concrete/soil Tf [N]

$$T_f = (V_c g_c + V_s g_s) f$$

where:

V_c = volume of concrete block, m^3
V_s = volume of soil above the concrete block, m^3
f = Friction coefficient (concrete/soil)

D. Balance of thrusts

A check has to be done that the passive soil reaction (T_S) plus the friction force (T_f) is higher than the thrust (F) as follows:

$$T_s + T_f \geq 15F$$

E. Maximum concrete's stress verification

A check must be done in order to verify that the concrete's stress due to thrust is lower than the allowable value.

F. Maximum compressive soil's stress verification

A check must be done in order to verify that the maximum compressive soil's stress due to passive thrust is lower than the allowable value.

16. SUBAQUEOUS INSTALLATION

The selection of GRP material for the laying of underwater pipelines offers many advantages connected to the material characteristics. GRP pipe is fully resistant to corrosion.

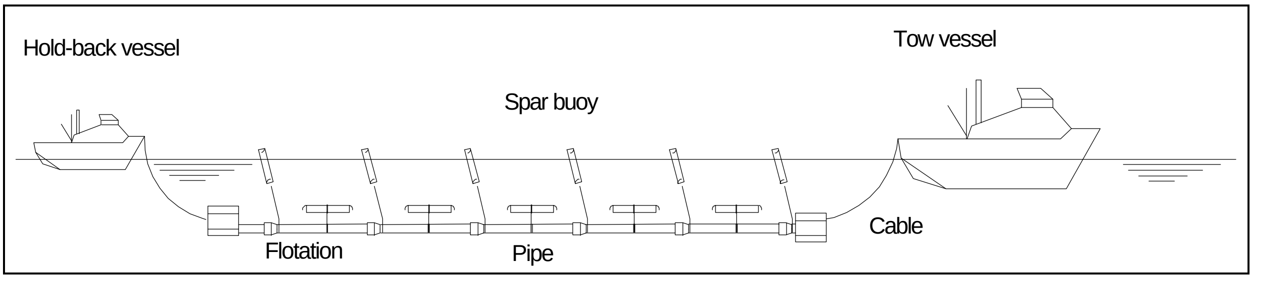
The following methods are used for off-shore GRP pipeline installations:

1. towing method;
2. bottom pulling method;
3. installation by crane barge.

1. Towing method

The pipeline string is prepared on-shore, then launched at sea by pulling method but at a certain elevation on the seabed, where it is maintained and finally towed to the installation place.

Spar buoys are generally used to limit the amount of surface motion transferred to the



pipeline.

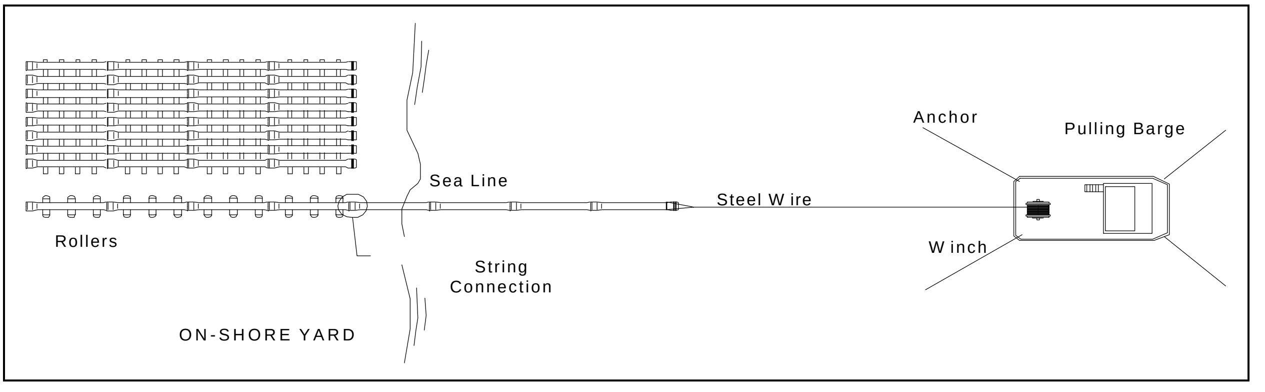
2. Bottom pulling method

This method is implemented by assembling on-shore strings of GRP pipe and by pulling them along the designed route axis trough a winch-cable system operated from a terminal located on barge.

The use of this technique implies the availability of an on-shore leveled area, where it is possible to preassemble flanked long strings of GRP pipe. Strings are launched in sequence by transferring each string on the launch line. GRP pipeline is pulled trough a which-cable system, hooked to a pulling head, connected to the source of the first string.

Once a GRP pipe string has been launched, next string is transferred on the towing line and connected to the previous one. Joining operations are implemented on-shore.

This method allows the contemporary launching of more than one parallel pipelines. Pipes may be launched empty, flooded or lightened by means of floats. Pipeline may advance directly on the seabed previously prepared or inside a pre-excavated submarine trench.

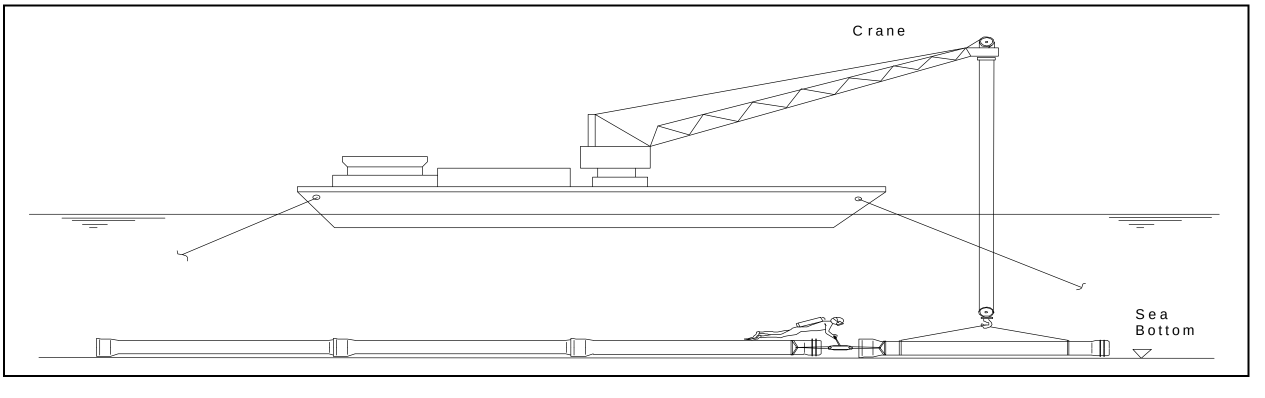


3. Installation by crane barge

This is probably the most used method nowadays, specially for large diameter pipes. The semi-mobile or towed barge has to have suitable dimensions in order to contain all equipment required for stowing and joining pipe lengths.

The barge dimensions, in addition to joining and launch operations, affect the progress of the work. Each pipe length is raised by the barge crane and lowered into to sea, where it is laid on the prepared seabed near the already laid pipe length.

The connection of pipe lengths is performed by skilled divers by means of hydraulic jacks, which can be applied to collars mounted on the pipe ends.



17. STORAGE, HANDLING, REPAIRS

Pipes and fittings should be kept on the cradles used for shipment. When this is not practical, pipes can be stored on sand ground and or on wood joists.

Pipes and fittings must be stored away from possible sources of flames, such as flammable liquids.

17.1 FIELD WELDING MATERIALS

The average standard life of welding materials is 6 months for resins, if properly stored indoors at a maximum temperature of 25 °C. Should the storage temperature be higher than 25 °C, the standard life of resins will be shortened and will be as lower as the outside room temperature is higher. In any case the storage temperature must be lower than 40 °C. Iniziative Industriali strongly suggests a storage temperature not higher than 25 °C.

Glass materials do not require particular storage conditions and do not present particular stability problems. Nevertheless it is advisable a storage room having a temperature not higher than 40 °C and a humidity not higher than 75%.

Resins are to be stored in their original drums, which guarantees the absolute dark. Glass materials are to be stored in their original packages. Both drums and packages must be opened provided the product is going to be used within a short time.

Welding materials are highly flammable. They must be protected from exposure to conditions which might produce combustion, such as open flames and heat sources.

Promoter material shall not be stored in the same area as other weld materials, particularly the organic peroxides.

17.2 HANDLING

Pipe lifting is done with slings of adequate strength and of such construction as not to damage pipe.

Straight continuous lengths of pipe are capable of being lifted at one point. However, due to the very smooth surface, it is safer to lift pipes at two points symmetrical with respect to pipe center.

Running of lifting rope inside the pipe shall never occur.

Pipe assemblies fabricated of multiple sections may require two points lifting.

While handling the pipes, impacts must be avoided, particularly of pipe ends.

17.3 INSPECTION AND REPAIRS

Upon arrival to the site or upon opening of cradles all pipes and fittings must be carefully visually inspected internally and externally. Damages are to be repaired as follows.

Surface Scrape

Pipe Interior: Glaze removal, then post coating with previously prepared resin must be done.

Pipe Exterior: No repair is generally required.

Surface cracks

Pipe Interior

a) The damaged area has to be ground up to the end of liner with sand paper or, better, an electrical grinder. Surface to be repaired has to be cleaned;

b) The ground surface has to be washed with acetone to remove dust;

c) A brush application of a thin coat of previously prepared resin onto the surface to be repaired;

d) Glass "E" mat is applied, saturated with resin, by using a brush;

e) Air bubbles are squeezed out using a roller;

f) Steps(d) and (e) must be repeated up to the liner thickness;

g) A glass surfacing "C" veil is applied and saturated with resin using a brush;

h) After one hour the resin will have hardened. Then shall be ground to an even surface and paint with paraffined resin (postcoat).

Pipe Exterior

a) The damaged area has to be ground as much as needed to remove the crack. Use sand paper or, better, an electric grinder. Surface to be repaired has to be clean;

b) Ground surface has to be washed with acetone to remove dust;

c) A brush application is done of a thin coat of previously prepared resin onto the surface to be repaired;

d) A layer is applied of glass "E" mat, saturated with resin by using a brush;

e) Air bubbles are squeezed out using a roller;

f) Steps (e) and (f) must be repeated in order to build up the thickness removed;

g) After one hour the resin will have hardened. Then paint with paraffined resin (postcoat) is carried out.

If the pipe is not repairable, the damaged area will be cut and rejected. When the pipe is already installed, the rejected section will be substituted with a section of new pipe of the same length, connected to the line with butt and strap joint.

18. OTHER CONSIDERATIONS

18.1 EARTHQUAKE

Earthquake displays its action along the three space directions, but only two of them (vertical and parallel directions to pipeline) have practical effects.

Vertical action

Earthquake action is converted into an increased value of gravity acceleration, that means an higher soil load on pipeline and a shear action on the pipe.

Parallel action

Soil movement along the pipeline determines, because of the friction between soil and pipeline, the sliding of pipeline joints if they are bell and spigot double O-ring type, or an axial stress if joints are bell and spigot double O-ring key lock type.

Earthquake action along the direction normal to pipeline and parallel to ground is negligible.

Seismic acceleration calculation

Vertical and horizontal accelerations, due to earthquake, are calculated as follows:

$a_v = m\ C\ I\ g$

$a_h = R\ C\ I\ g$

where :

- a_v = *vertical acceleration, m/s^2*
- a_h = *horizontal acceleration, m/s^2*
- m = *dimensionless coefficient, usually = 2*
- C = *seismic intensity coefficient = (S-2)/100*
- I = *seismic protection coefficient, usually = 1.2*
- R = *response coefficient of structure*
- g = *gravity acceleration, 9.81 m/s^2*
- S = *seismic grade (S>=2), usually = 9*

R (response coefficient) is assumed as a function of the fundamental period T_O of the structure, for oscillations along the considered direction:

when $T_O > 0{,}8$ s $\qquad R = 0.862 / T_O^{0.667}$

when T_0 <= 0.8 s R = 1

In case of indetermination of T_0 a value of R equal to 1 (maximum value) shall be assumed.

Vertical and horizontal accelerations, due to earthquake, are:

$a_v = 2 * (9 - 2) / 100 * 1.2 * g = 0.17\ g = 1.65\ m/s^2$

$a_h = 1 * (9 - 2) / 100 * 1.2 * g = 0.084\ g = 0.82\ m/s^2$

Acceleration during earthquake shall be:

Vertical action

$a_v + g = 1.17\ g = 11.5\ m/s^2$

Horizontal action

$a_h = 0.08\ g = 0.82\ m/s^2$

Check of pipe buckling during earthquake

Vertical action increases the weights of ground and live load operating on the pipeline. This condition determines a reduction of the safety factor to buckling.

Buckling is checked at depth foreseen by the design through the following formulae (AWWA C950-88):

$q_a = (1/FS)(32\ R_w B'\ E'\ S)^{1/2}$ (see 11.3)

$$q_{ex} = \left(R_W \frac{W_C}{D} + \frac{W_L}{D}\right)\frac{a_v + g}{g}$$

q_{ex} = external loads, N/mm^2

$q_a /\ q_{ex} \geq 1$

18.1.1 Seismic strain of ground

In order to calculate the seismic action along the direction parallel to pipe it is necessary to consider the strain of ground during earthquake:

$$\varepsilon_g = \left(T_g a_h\right) / \left(2\pi v_s\right)$$

where:

T_g = seismic wave period, s
a_h = horizontal acceleration, m/s^2
v_s = propagation speed of the seismic wave, m/s

18.1.2 Axial strain of pipe

Bell and Spigot Double O-ring Lock Joint

Bell and Spigot Double O-ring Lock Joint transmits axial stresses and allows rotation between a pipe length and its adjacent.

We have to determine the pipe's axial strain due to earthquake, add the strain due to working pressure and verify that the total strain is less than the axial allowable strain.

Bell and Spigot Double O-ring

Bell and Spigot Double O-ring Joint does not transmit axial stresses and allows rotation between a pipe length and its adjacent.

The pipe's axial strain due to earthquake must be determined and checked that joint sliding does not allow the slipping of the spigot out of the bell.